PB81-107088

Wastewater Contaminate Removal for Groundwater Recharge at Water Factory 21

Stanford Univ., CA

Prepared for

Municipal Environmental Research Lab.
Cincinnati, OH

Aug 80

U.S. Department of Commerce
National Technical Information Service
NTIS

United States
Environmental Protection
Agency

Municipal Environmental Research
Laboratory
Cincinnati OH 45268

EPA-600/2-80-114
August 1980

Research and Development

PB81-107038

EPA

Wastewater Contaminate Removal for Groundwater Recharge at Water Factory 21

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TECHNICAL REPORT DATA
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1. REPORT NO. EPA-600/2-80-114	2.
3. RECIPIENT'S ACCESSION NO. PB81 107088	
4. TITLE AND SUBTITLE WASTEWATER CONTAMINATE REMOVAL FOR GROUNDWATER RECHARGE AT WATER FACTORY 21	5. REPORT DATE August 1980 (Issuing Date) 6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S) Perry L. McCarty, Martin Reinhard, James Graydon, Joan Schreiner, Kenneth Sutherland, Thomas Everhart, and David G. Argo	8. PERFORMING ORGANIZATION REPORT NO.
9. PERFORMING ORGANIZATION NAME AND ADDRESS Department of Civil Engineering Stanford University Stanford, California 94305	10. PROGRAM ELEMENT NO. 35B1C, SOS#4, Task 07 11. CONTRACT/GRANT NO. Grant No. EPA-S-803873
12. SPONSORING AGENCY NAME AND ADDRESS Municipal Environmental Research Laboratory--Cin.,OH Office of Research and Development U. S. Environmental Protection Agency Cincinnati, Ohio 45268	13. TYPE OF REPORT AND PERIOD COVERED Final 7-77 to 12-78 14. SPONSORING AGENCY CODE EPA/600/14

15. SUPPLEMENTARY NOTES See also "Water Factory 21: Reclaimed Water, Volatile Organics, Virus, and Treatment Performance," EPA-600/2-78-076, NTIS PB285053/AS. Project Officer: John N. English 513/684-7613.

16. ABSTRACT

This is the second report in a series which describes the performance of Water Factory 21, a 0.66 m^3/s advanced wastewater treatment plant designed to reclaim secondary effluent from a municipal wastewater treatment plant so that it can be used for injection and recharge of a groundwater system. Included in this evaluation of the second one and one-half years of operation are data on the efficiency and reliability of individual processes and the overall system for removal of general inorganics, heavy metals, virus, and a broad range of organic materials. Probability distributions of the various contaminants in the influent and effluent from the system are included along with a general statistical analysis of data. During the first six months of this evaluation, the influent to Water Factory 21 was trickling filter treated wastewater, and during the last year, the influent was activated sludge treated wastewater from the same municipal system. Processes included in the plant are lime treatment, air stripping, filtration, activated carbon, adsorption, reverse osmosis, and chlorination.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
Waste Treatment, Treatment, Water Reclamation, Advanced Wastewater Treatment, Nutrients, Virus, Organic Compounds, Potable Water, Microorganisms, Trace Organic Materials, Toxic Substances, Heavy Metals, Wastewater Treatment, Wastewater Reuse, Groundwater Injection, Activated Carbon, Reverse Osmosis, Air Stripping	Reuse, Heavy Metals, Haloforms, Trihalomethanes, Virus, Toxic Substances, Reclamation, Wastewater	13B

18. DISTRIBUTION STATEMENT Release to Public	19. SECURITY CLASS (This Report) Unclassified	21. NO. OF PAGES
	20. SECURITY CLASS (This page) Unclassified	22. PRICE

EPA Form 2220-1 (Rev. 4-77)

* U.S. GOVERNMENT PRINTING OFFICE 1980-657-165/0139

EPA-600/2-80-114
August 1980

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FOREWORD

The Environmental Protection Agency was created because of increasing public and government concern about the dangers of pollution to the health and welfare of the American people. Noxious air, foul water, and spoiled land are tragic testimony to the deterioration of our natural environment. The complexity of that environment and the interplay between its components require a concentrated and integrated attack on the problem.

Research and development is that necessary first step in problem solution and it involves defining the problem, measuring its impact, and searching for solutions. The Municipal Environmental Research Laboratory develops new and improved technology and systems for the prevention, treatment, and management of wastewater and solid and hazardous waste pollutant discharges from municipal and community sources, for the preservation and treatment of public drinking water supplies, and to minimize the adverse economic, social, health, and aesthetic effects of pollution. This publication is one of the products of that research; a most vital communications link between the researcher and the user community.

This report describes the performance of Water Factory 21, a 0.66 m^3/s advanced wastewater treatment plant designed to treat municipal wastewater so that it can be used to recharge a groundwater system. Through this project groundwater supplies are being replenished, saltwater-endangered aquifers are being protected, and water is being reclaimed for future use.

Francis T. Mayo, Director
Municipal Environmental
Research Laboratory

ABSTRACT

Water Factory 21 (WF-21) in Orange County, California, is a 0.66 m^3/s (15 mgd) advanced wastewater treatment plant that has been designed to reclaim biologically treated municipal wastewater to supply the injection water for a seawater-barrier system. Processes included are lime treatment, air stripping, filtration, activated-carbon adsorption, reverse osmosis, and chlorination. This study was undertaken because of interest in the use of reclaimed water to augment domestic water supplies.

There have been three distinct periods of operation at WF-21. A previous report (2) described results from the first two periods. This report presents a comparison between results from the second period with trickling-filter influent and the first nine months of the third period when higher-quality activated-sludge effluent was treated.

A statistical analysis was made of concentration variations with time for each contaminant at each sample location, and indicated that in general the probability variations followed a lognormal distribution. The report contains summaries of inorganic, organic, and biological contaminant geometric means, spread factors, removal efficiencies, and 95% confidence intervals.

In the influent waters to WF-21 the geometric mean concentrations only of cadmium, coliforms, and turbidity exceeded EPA National Interim Primary Drinking Water Regulations (NIPDWR) maximum contaminant levels (MCL) during the three periods of operation as did chromium during the first two periods. Following treatment at WF-21 and for at least 98 percent of the time, all contaminants during all periods of operation were below NIPDWR MCL values. Additional quality standards have been imposed by regional authorities. These standards on the average have been met. At least 2 percent of the time the MCls for ammonia of 4 mg/l, for fluoride of 0.8 mg/l, for boron of 0.5 mg/l, and for electrical conductivity of 900 µS/cm have been exceeded.

Lime treatment, activated-carbon adsorption, and reverse osmosis were the most effective processes in overall organics removal as measured by COD or TOC. An average COD removal of 88 percent was obtained during the second period from 141 to 17 mg/l, and of 74 percent during the third period from 47 to 12 mg/l by processes through activated-carbon adsorption. Reverse-osmosis treatment during the latter period resulted in additional COD removal down to a geometric mean of 1.3 mg/l.

Over 100 trace organic substances were found in influent waters to WF-21 and of these, about 30 were monitored regularly. The two processes found most efficient in removal were air stripping and activated-carbon adsorption, and overall removals were generally greater than 90 percent.

Viruses were routinely found in influent waters to WF-21. They were detected in the effluent only twice during the second period when activated-carbon towers were operated in the upflow mode and some carbon attrition resulted, but were not detected in the effluent during the third period.

This report was submitted in fulfillment of Research Grant No. EPA-S-803873 by the Orange County Water District under the sponsorship of the U.S. Environmental Protection Agency. This report covers the period August 1, 1977, to December 31, 1978, and was completed January 1, 1980.

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ACKNOWLEDGMENTS

Dr. Lawrence Leong and Dr. Rhodes Trussell, James M. Montgomery, Consulting Engineers, Inc., were responsible for viral assay and technical direction for the virus phase of the project. Ms. Betsy Martin, Orange County Water District, participated in the field virus concentrations. Also, appreciation is extended to the California Department of Public Health for their advice and assistance in the virus assays.

In addition to the support provided by the Orange County Water District and the U.S. Environmental Protection Agency, project financial assistance was provided by OWRT, U.S. Department of the Interior through Grant 14-34-001-7503, the California Department of Water Resources through Grant No. B52353, and various member agencies of WaterCare.

SECTION 1

INTRODUCTION

The Orange County Water District (OCWD) has constructed Water Factory 21 (WF-21) and a series of injection wells near the Pacific Coast in order to reduce seawater intrusion into the groundwater supply by recharge of reclaimed wastewater (9). Water Factory 21 is a 0.66 m^3/s (15 mgd) advanced wastewater treatment plant which was designed to improve the quality of biologically treated municipal wastewater so that it could be used to provide the injection water needed for the seawater barrier system. Processes included in this facility are lime treatment for suspended solids, heavy metals and organics removal; air stripping for ammonia and volatile organics removal; recarbonation for pH adjustment; chlorination for algae control; and filtration and activated-carbon adsorption for organics and additional suspended solids removal; reverse osmosis for demineralization and organics removal, and final chlorination for disinfection and partial ammonia removal.

Because of the high quality of water reclaimed by WF-21, interest has increased in the potential of using the reclaimed and injected wastewater to augment the domestic water supply. However, inadequate knowledge of inorganic, organic and biological constituents remaining after advanced wastewater treatment has caused concern among health agencies responsible for protecting the safety of groundwater supplies. Because of such concern, this study was undertaken to: (1) characterize the quality of Water Factory 21 effluent, (2) assess the reliability of treatment plant operation for removal of trace contaminants, and (3) evaluate the effectiveness of the individual processes and processes in combination for removing materials of public health concern.

This report is a summary of the results of inorganic and organic analyses, and viral assays, and an evaluation of the performance for the first three years of operation of Water Factory 21. It provides a more detailed analyis of results than presented earlier for the first one and one-half years of operation (1), and also provides additional data since the influent to WF-21 was changed from a trickling filter treated municipal wastewater to the present activated sludge treated municipal wastewater.

SECTION 2

CONCLUSIONS

1. The change in influent water to Water Factory 21 from a trickling filter to an activated sludge treated wastewater with less industrial waste contribution has resulted in better influent water quality and more economical plant operation.

2. The variations in inorganic and organic constitutent concentrations in the influent, effluent, and intermediate points are generally described well by lognormal distributions.

3. Several processes are effective in organics removal, especially high lime treatment, air stripping, activated carbon adsorption, and reverse osmosis.

4. Each of the above processes is effective in removing different organic fractions: lime treatment removes suspended organics and some dissolved organics; air stripping removes a variety of volatile organics including trihalomethanes, chlorinated solvents containing one and two carbon atoms, chlorinated benzenes, and some aromatic hydrocarbons; activated carbon removes intermediate and higher molecular weight nonpolar organics including some aromatic hydrocarbons, some phthalates, and heavier chlorinated hydrocarbons such as chlorinated benzenes and PCBs; reverse osmosis is mainly effective in removing higher molecular weight humic materials as measured by COD.

5. The total treatment system through reverse osmosis at Water Factory 21 produces a water with an effluent COD averaging less than 2 mg/l, and a TOC of less than 1 mg/l.

6. Heavy metals are removed effectively by lime treatment and reverse osmosis, and in some cases by activated carbon adsorption.

7. No single process is capable of removing the entire range of organic contaminants present in secondary municipal effluent, but most can be removed by at least one of the several processes used in the Water Factory 21 system. In general, similar compounds (physically and chemically) are removed by the same processes.

8. Enteric virus are prevalant in influent waters to Water Factory 21, but are effectively removed by treatment. Viruses detected in the effluent on two occasions appear to be associated with excessive particulates from the activated carbon columns when previously operated in an upflow mode. None have been detected during the third period since operated in the downflow mode.

9. Water Factory 21 has a high reliability for producing a water with contaminant levels below the maximum contaminant levels set forth in current and proposed EPA National Interim Primary and Secondary Drinking Water Standards, especially during the third period when water of improved quality was being treated.

10. During the third period, only cadmium, coliforms, turbidity, chromium, and fluoride exceeded the National Primary Drinking Water MCL levels more than 2% of the time in the Water Factory 21 influent, only chromium and perhaps mercury exceeded the MCL levels more than 2% of the time in the activated carbon effluent.

11. Reverse osmosis demineralization was effective in reducing the mineral content of the reclaimed water sufficiently to satisfy the proposed National Secondary Drinking Water Criteria.

12. Treated water from Water Factory 21 is greatly improved in quality over influent water; however, trace organics can still be detected. Since no standards exist for these materials in reclaimed waters, questions of reliability for their removal cannot be adequately addressed. Many of the trace organics found in the effluent appear to be the result of chlorination for disinfection. Most of those generally believed to be of industrial origin are reduced to the low nanogram per liter range by treatment.

SECTION 3

RECOMMENDATIONS

1. Bioassay techniques should be used in further efforts to assay the suitability of reclaimed municipal wastewaters for direct or indirect use as part of a potable supply.

2. More effort needs to be placed on the development and evaluation of surrogate and collective parameters for routine monitoring of the quality of reclaimed waters, and for evaluating efficiency of treatment processes.

3. A better understanding is needed of coatings used to prevent corrosion of tanks in water treatment plants as these appear to contribute to the level of trace contaminants in treated effluents.

4. Analytical techniques should be improved for more precise quantification and more complete identification of the many trace organics present in municipal wastewaters.

5. The experiences at Water Factory 21 are applicable to the treatment of drinking water supplies taken from highly contaminated sources. It is recommended that these experiences be reviewed by those contemplating the upgrading of drinking water quality.

6. Since chlorination produces most of the trace organics of health concern found in Water Factory 21 effluent, alternatives to chlorination need evaluation.

SECTION 4

WATER FACTORY 21 PROCESS DESCRIPTION

GENERAL DESCRIPTION

Water Factory 21's advanced wastewater reclamation facilities were designed to treat 0.66 m^3/s (15 mgd) of unchlorinated secondary effluent from municipal wastewater treatment by the processes indicated in Figure 1. These processes include lime clarification with sludge recalcining, air stripping, recarbonation, prechlorination, mixed-media filtration, granular activated carbon (GAC) adsorption with carbon regeneration, final chlorination and reverse osmosis (RO) demineralization. Also indicated in Figure 1 are the sample locations, designated as Q1, Q2, etc. Detailed design criteria for each process are contained in Appendices A and B. All unit processes were designed as dual or parallel units, and operation of any given unit process was at or near design capacity during the total study period. Following is a general description of each process followed by a discussion of the three major operational periods for WF-21.

PROCESS DESCRIPTION

Chemical Clarification

Chemical clarification is accomplished in separate rapid mix, flocculation, and sedimentation basins. Lime is used as the primary coagulant and is added in slurry form to the rapid mix basin. Lime feed is automatically controlled to achieve an optimum pH of 11.0. A lime dose of 350-400 mg/l as calcium oxide is sufficient to maintain this pH level. The three-stage flocculation basins are operated with G values of 100, 25, and 20 s^{-1} in the first, second, and third basins, respectively. Detention time is approximately 10 minutes in each compartment. An anionic polymer dose of approximately 0.1 mg/l is used as a settling aid in the third-stage basin. The water flows from the bottom of this basin to the settling basin, which is equipped with inclined settling tubes to improve clarification. Results of lime clarification have shown this process to be effective in reducing turbidity, phosphates, organics, and suspended solids.

Air Stripping

Following settling, air stripping is accomplished in a counter-current induced draft tower with a design air to water ratio of 3000 m^3/m^3. Originally the tower was operated to strip ammonia nitrogen from the secondary municipal effluent. However, changes in the secondary treatment system

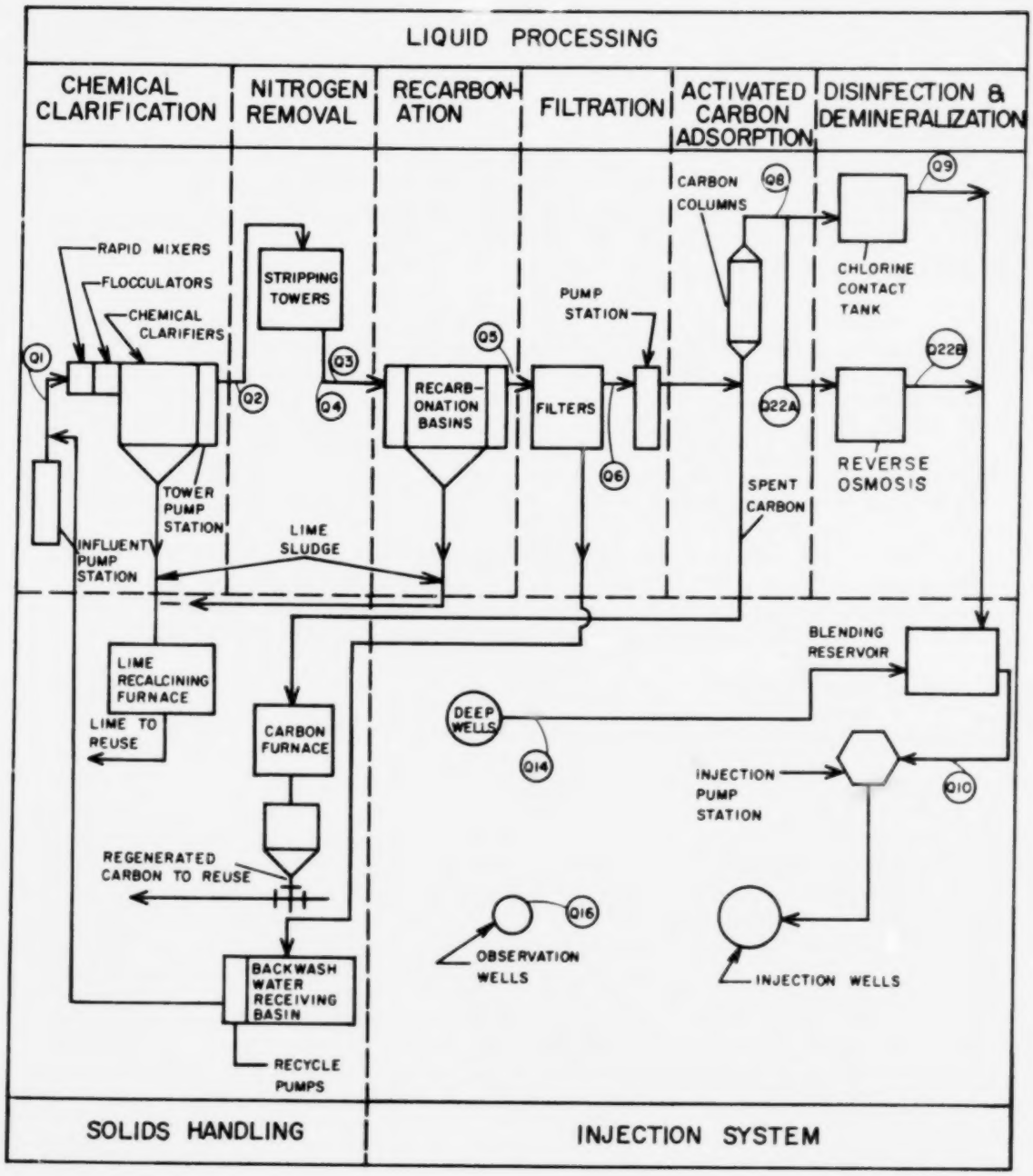

Figure 1. Flow schematic and sampling locations for Water Factory 21

beginning with period three as described later have reduced ammonia concentrations in the WF-21 influent to levels below 5 mg/l. Thus the ammonia tower fans have been shut down and the air stripping process is now used for removal of volatile organics only. The water from the chemical clarifier is pumped to the top of the stripping towers, where it is allowed to cascade over 7.6 m of polypropylene splash-bar packing. The only draft at present is due to natural ventilation. While little ammonia removal is experienced through the towers, this process has been shown to be effective for removing a wide range of volatile organic compounds.

Recarbonation

Following air stripping, the pH of the treated wastewater is adjusted in the recarbonation basin. Carbon dioxide from lime recalcining is added in single stage to lower the pH to approximately 7.5. The plant was originally designed for two-stage recarbonation, but this created operational problems with fine calcium carbonate precipitates and so the present single-stage operation was instigated. The recarbonation basin also serves as a chlorine contact chamber. Generally 10 mg/l of chlorine is added primarily as a disinfectant, but it also controls algal growth. During certain periods the chlorine dosages are increased to provide for partial ammonia nitrogen removal. During this phase of operation, a chlorine-to-ammonia nitrogen weight ratio of 9 or greater is required to reduce ammonia nitrogen levels to less than 1 mg/l. Chlorination at this point generally results in the production of halogenated organic compounds and so alternatives are being examined.

Mixed-Media Filtration

The recarbonated effluent passes through open gravity, mixed-media filter basins designed for a hydraulic loading rate of 0.2 $m^3/m^2/min$. The filter media, 0.76 m deep, consist of layers of coarse coal, silica sand, and garnet, supported by a layer of silica and garnet gravel with a Leopold underdrain. Alum and polymer are occasionally added to improve clarification.

Granular Activated-Carbon Adsorption

The water is then pumped to the top of one of seventeen downflow GAC contactors which contain Calgon Filtrasorb 300 carbon. The contactors operate in parallel, each having an empty-bed contact time of 34 minutes. The hydraulic loading rate for each column is 0.2 $m^3/m^2/min$. Following GAC adsorption, the flow from the AWT plant is presently divided. Two-thirds goes to the final chlorination basin for post-chlorination, followed by 30 minutes of contact time at design flow. The other one-third is diverted to the 0.22 m^3/s RO plant which removes dissolved solids from the reclaimed wastewater.

Reverse Osmosis

A flow diagram of the full-scale RO plant is shown in Figure 2. Included in this process are feeding of sodium hexametaphosphate as a scale-precipitation inhibitor, addition of chlorine to control biological growth within the membrane modules, and 25-micron filtration to remove particulates. The water is then pressurized by vertical turbine feed pumps to a total dynamic head of 420 m water. Acid is injected into the high-pressure feed header to adjust pH to approximately 5.5 before the water is applied to the RO membranes. The RO plant is designed to provide 90 percent salt removal while achieving 85 percent overall water recovery. The demineralized water receives post-treatment in two packed-tower decarbonators to air-strip the dissolved carbon dioxide which results from pH adjustment to 5.5. These decarbonators have been found to be efficient in removing volatile trace organics. A detailed description of the RO plant's design criteria is provided in Appendix B.

PERIODS OF OPERATION

WF-21 has been in operation since January 1976. Operation since that time can be divided into three periods as summarized in Table 1.

TABLE 1. DIFFERENT OPERATIONAL PERIODS AT WATER FACTORY 21.

Period	Dates	Operational Characteristics
1	Jan. 1976 to Oct. 1976	Trickling filter influent, no breakpoint chlorination, no reverse osmosis, no injection
2	Oct. 1976 to March 1978	Trickling filter influent, breakpoint chlorination, no reverse osmosis, injection
3	Mar. 1978 to Jan. 1979	Activated Sludge influent, no forced circulation in stripping, partial ammonia removal by chlorination, reverse osmosis, injection

During the first period, from January to October 1976, no breakpoint chlorination was used for NH_3 removal. During the second period, from October 1976 to March 1978, breakpoint chlorination was instigated as was groundwater injection. During the third period, from March 1978 to the present, the influent to Water Factory 21 was changed from a partially treated trickling-filter effluent to a well-treated activated-sludge effluent, both of which are unchlorinated. Also, the Orange County Sanitation District, which supplies the secondary effluent, segregated a large portion of industrial wastes away from the activated-sludge system feeding Water Factory 21. These changes resulted in significant improvements in the quality of water received by Water Factory 21. The 0.22 m^3/s

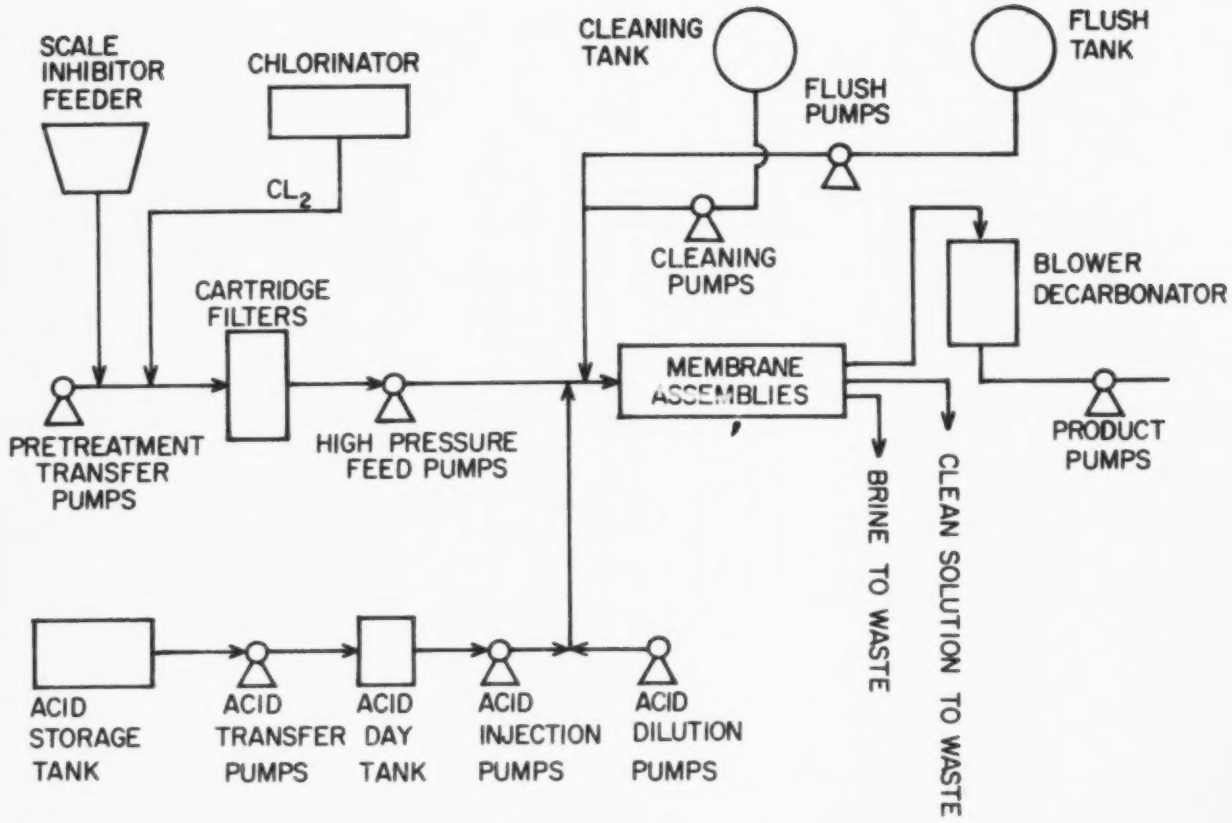

Figure 2. Reverse osmosis plant flow diagram.

reverse osmosis plant was added to the Water Factory 21 treatment system late in the second period and has been used throughout the third period. Operation during the first period was covered in a previous report (1). This report covers results from the second and third periods only.

COMPARISON BETWEEN DESIGN AND ACHIEVED FLOW RATES

WF-21 has not been operated at the design flow rate of 0.66 m^3/s throughout its history of operation. Because it is generally possible to vary the number of units in operation for any given process, the percentage of design flow rate for the different processes could be varied. Also, it is not necessary to continuously produce water for the seawater barrier system, so that WF-21 can and has been shut down periodically for routine maintenance or plant modifications.

Table 2 is an overall summary of the average flow rate to the various operating processes in percentage of the design flow rate for the second and third periods. Figure 3 presents a more detailed picture of the relative flow rates for these two periods, including the time when the plant was shut down for maintenance and process modification. Also shown are the chlorine dosages to the recarbonation basin and the final chlorine contact basin. During the second period chlorine was added in relatively high concentration to the recarbonation basin to achieve reduction in ammonia concentration. Later during the second period, chlorination for ammonia removal was moved to the final contact tanks. Some chlorine addition to the recarbonation basin was maintained, however, for the control of algae.

TABLE 2. AVERAGE FLOW RATES TO VARIOUS PROCESSES AS PERCENTAGE OF DESIGN FLOW RATE DURING PERIODS TWO AND THREE

Process	Period Two*	Period Three*
Clarification	58 ± 21	79 ± 30
Air Stripping	46 ± 18	89 ± 28
Recarbonation	83 ± 22	90 ± 30
Activated Carbon	64 ± 18	96 ± 20
Final Chlorination	25 ± 5	51 ± 16
Reverse Osmosis	68 ± 25	99 ± 14

*Values given as percent of design flow rate ± standard deviation

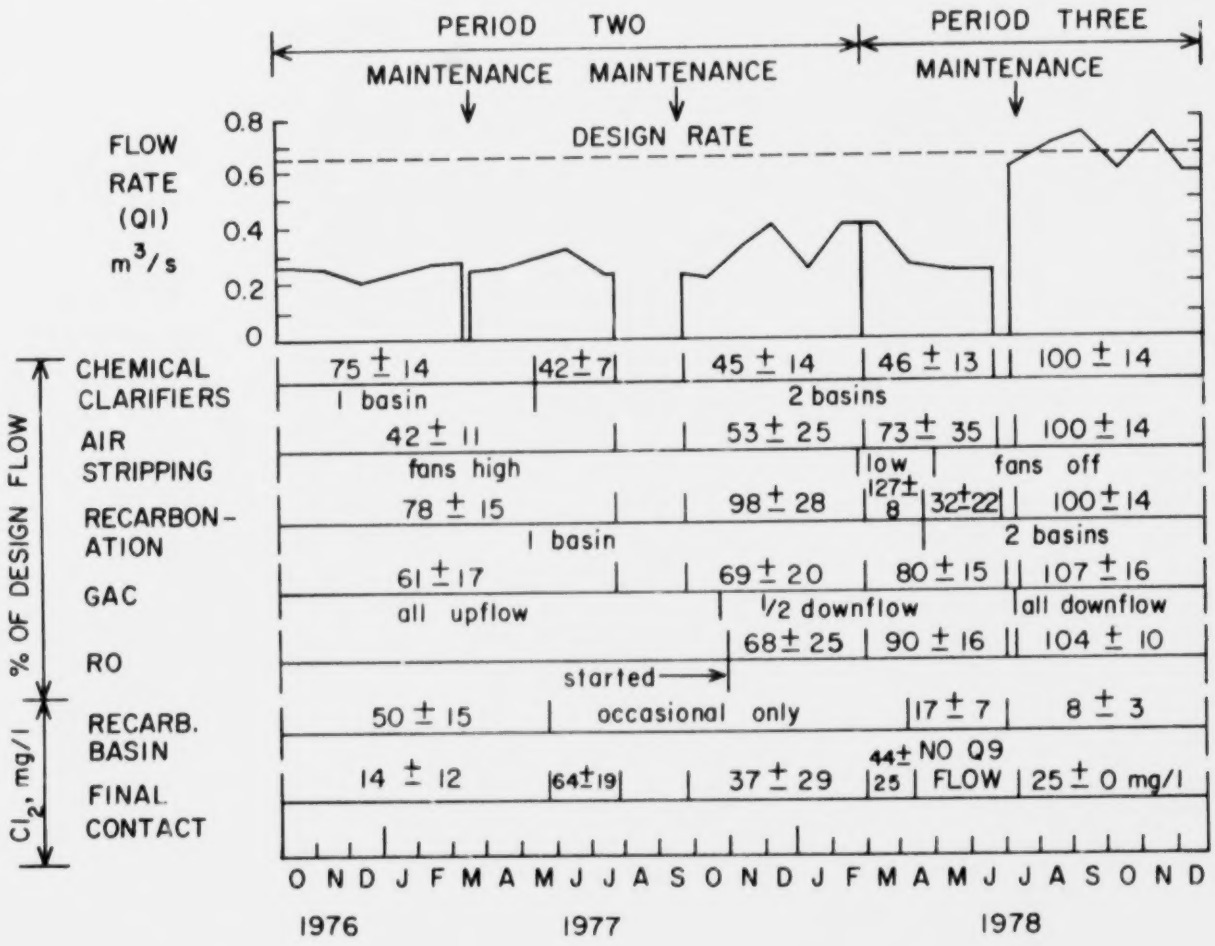

Figure 3. Summary of flow rates to various unit processes and applied chlorine concentrations during the second and third periods.

Most processes were operated below their design flow rate until the last six months of the third period. Sampling for trace organics was intensified during this latter period since this represents the normal mode of operation which is planned for WF-21.

SECTION 5

SAMPLING AND ANALYTICAL PROCEDURES

SAMPLING

Analyses for chemical oxygen demand (COD), total organic carbon (TOC), inorganic constituents, and heavy metals were conducted on daily composite samples by the Water Factory 21 analytical laboratory. Viral analyses were conducted by James Montgomery Engineers, Pasadena, California. Specific organic constituents were analyzed in the Stanford Water Quality Control Research Laboratory. Grab and composite samples were stored under refrigeration prior to organic analysis. Composite samples were prepared by mixing equal volumes of nine grab samples taken at three-hour intervals over a 24-hour period. Samples analyzed at Stanford were shipped by air in insulated containers, and arrived on the same day. Specific methods used in sample preservation prior to analysis are given under the specific analytical procedures which follow. Sampling locations are designated by numbers preceded by the letter Q in Figure 1.

GENERAL INORGANICS AND HEAVY METALS

The sampling and analytical procedures for general inorganics and heavy metals are described for two distinct periods. First is the period prior to injection and encompasses January, 1976, through June 1976. The other period coincides with the start of injection, from October 1976 through June, 1977. Table 3 indicates the sampling schedule and frequency for all inorganic and heavy metal analyses for the period after October, 1976 covered by this report. All analyses were conducted in accordance with Standard Methods (2). Table 4 summarizes the particular procedures from Standard Methods used for each parameter.

ORGANICS

COD and MBAS were determined on daily composite samples using the standard procedures listed in Table 4. TOC was determined on daily composite samples using a Beckman 915A TOC analyzer. The characterization of trace organic substances in water was performed for a number of selected substances on a routine basis. A broad and detailed characterization was attempted with some of the samples.

The general scheme which was applied for the analysis of specific organics is depicted in Figure 4. This procedure has evolved during this study.

TABLE 3. WATER FACTORY 21 SAMPLING SCHEDULE

Parameter	Sample Points: Plant Influent Q1	Clarifier Effluent Q2	Ammonia Tower #2 Effluent Q4	Filter Effluent Q6	Carbon Effluent Q8	Chlorine Contact Basin Effluent Q9	Blended Water Q10	RO Plant Influent Q22A	RO Plant Effluent Q22B
pH	DC	2G				DC		WG	
EC	CA	CA				CA	CA	DG	DG
TDS	WC					WC	WC	WC	
Turbidity	CA	CA		CA			CA		
NH_3-N	DC	DC	WC				DG		
NO_3-N	WG					WG	WG	WG	WG
Total & Free Chlorine Res.						2G			
TOC				DC	WC				
COD	DC	DC		DC	DC		DC	DC	DC
MBAS	WC	WC			WC	WC	WC		
Phenol	WG	WG		WG	WG		WG		
Cyanide	WG					WG	WG		
Trace Elements [1]	MC	MC		MC	MC		WC		
Calcium	WC					WC	WC		
Mg	WC					WC	WC		
Total Hardness	WC					WC	WC	WC	WC
Sodium	WC					WC	WC	DC	DC
Sulfate	WC					WC	WC	DC	DC
Chloride	WC					WC	WC	DC	DC
PO_4-P	WC	WC							
TKN		DC				DC	DG		
ORG-N	DC	DG	WC			DC	DG		
F	WC					WC	WC		
B	WC					WC	WC		
Coliform	WG	WG		DG	DG	DG	DG		
Virus [2]	DG					DG			
Color	WC					WC	WC		

[1] Trace elements include: arsenic, chromium(VI), barium, copper, mercury, selenium, cadmium, silver, lead, zinc, Fe, Mn.

[2] Sampling and concentration on-site by B. Martin, analysis by Montgomery Engineers.

DC - daily composite (1 grab every 4 hr. 500-ml sample); DG - daily grab sample; 2G - one grab every 2 hr. (day-shift only); GM - once per month grab; WC - 24-hr composite taken once per week; CA - control panel value - online instrument average; WG - grab sample once per week.

TABLE 4. GENERAL ANALYTICAL PROCEDURES

Parameter	Method	Page Number from Standard Methods (2), 14th Edition
conductivity @ 25°C	direct, specific conductance meter	71
pH	direct, pH meter	460
total dissolved solids (TDS)	glass fiber filtration, water bath (100°C) and oven drying (180°C)	92
calcium	titration with EDTA	189
magnesium	atomic absorption, flame	148
sodium	atomic absorption, flame	250
potassium	atomic absorption, flame	234
aluminum	atomic absorption, graphite furnace	148
iron	atomic absorption, graphite furnace	148
manganese	atomic absorption, graphite furnace	148
silver	atomic absorption, graphite furnace	148
arsenic	atomic absorption, graphite furnace	148
barium	atomic absorption, graphite furnace	148
cadmium	atomic absorption, graphite furnace	148
chromium	atomic absorption, graphite furnace	148
copper	atomic absorption, graphite furnace	148
lead	atomic absorption, graphite furnace	148
selenium	atomic absorption, graphite furnace	148
zinc	atomic absorption, graphite furnace	148
mercury	flameless atomic absorption	156
alkalinity	as $CaCO_3$, titration with H_2SO_4	278
chloride	titration with $Hg(NO_3)_2$	304
fluoride	specific ion electrode	391
sulfate	turbidimetric	496
phosphate	ascorbic acid	481
nitrate-nitrogen	brucine sulfate	427
ammonia-nitrogen	1. Kjeldahl method	438
	2. phenate method	416
organic-nitrogen	Kjeldahl	437
boron	curcumin	287
methylene blue active substance (MBAS)	methylene blue	600
chemical oxygen demand (COD)	dichromate digestion	550
silica	molybdosilicate	487
hardness, total	EDTA	202
phenol	colorimetric (AAP)	582
dissolved oxygen	iodometric, azide modification	443
dissolved sulfide	methylene blue	503
coliform	membrane filter	928
fecal coliform	membrane filter	937
color	visual comparison	64
cyanide	distillation and colorimetric	361

TABLE 4. (CONTINUED)

Parameter	Method	Standard Methods (2), 14th Edition
residual chlorine	1. amperometric	322
	2. DPD	332
total organic carbon	combustion-infrared	532
odor	threshold procedure	*
radioactivity		
gross alpha	internal proportional count.	648
gross beta	internal proportional count.	648

*"Methods for Chemical Analysis of Water and Wastes," page 287, EPA-625-6-74-003 (1974).

VOA

The pentane-extraction procedure described by Henderson, et al, (3) was used for this analysis. Grab samples were placed in 50-ml hypovials capped with teflon seals and containing one ml of sodium thiosulfate and filled to prevent possible loss of volatile organics. They were refrigerated until sent (within 24 hours) by air in insulated containers to Stanford. The samples were then extracted with 1 ml of pentane containing an appropriate amount of internal standard (1,2-dibromoethane), and an aliquot of 5 µl was analyzed by gas chromatography on a 6 ft packed column (10% squalene on chromosorb W/AW) using an electron-capture detector. Results were integrated and computed by a System I integrator (Spectra Physics). Organics measured were most haloforms including chloroform, and various other halogenated one- and two-carbon organics. The detection limit was about 0.1 µg/l.

CLSA

Closed-loop stripping by the Grob procedure (4) allowed analysis for a broad range of volatile organics present in the ng/l range and above, such as solvents, petroleum products, and chlorobenzenes. However, several of the organics determined by VOA are not measured quantitatively by this method. Thus, VOA and CLSA are complementary procedures. One-liter bottles (solvent cleaned) were filled with daily composite sample and refrigerated until analyzed. Organics in 250-1000 ml of the sample were removed by recirculation of a small volume of air through the sample and over an activated charcoal filter for two hours. The filter was then extracted with 20 µl of CS_2, approximately 13 µl of which was recovered. An aliquot of 1.5 µl was used for high-resolution gas chromatographic (GC) analysis (Carlo Erba), using a glass capillary column (50 m UCON HB, Jaeggi Laboratory for GC, Trogen, Switzerland). The gas chromatograph was equipped with a Grob-type injector (Brechbuhler AG, Urdof, Switzerland). Flame-ionization detection was used. Chromatograms were analyzed with a Sigma

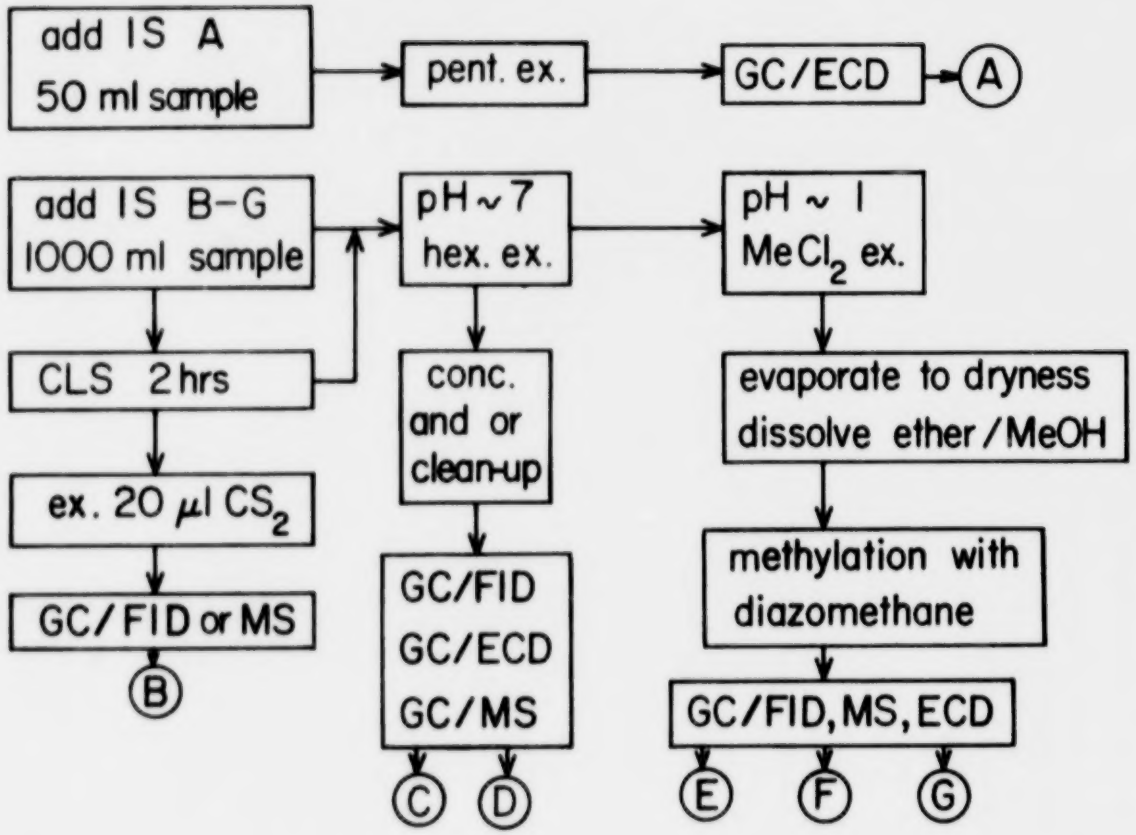

Figure 4. Analytical scheme for trace organics. A: VOA compounds, B: CLSA compounds, C: Pesticides, D: Polyaromatic hydrocarbons, E: Phenols, F: Aliphatic acids, and G: Aromatic acids.

10 reporting integrator. For mass spectrometric (MS) identification (Finnigan 4000), a 3-µl aliquot was used. Monochlorinated normal alkanes (1-Cl-C_8, 1-Cl-C_{12}, and 1-Cl-C_{16}) were added to samples as internal standards prior to air stripping.

Solvent Extraction Without Methylation (SEA).

Solvent extraction analysis was used for the non-volatile organics. A Finnigan 9610 Model gas chromatograph equipped with a glass capillary column (50 m SE 54, Jaeggi Laboratory), and a wide-range electron capture detector (ECD, Analog Technology Model 140) was used. The interface consisted of a temperature-stabilized heating block for pre-heating argon/methane (95/5) pure gas and capillary column inlet. One liter of daily composite collected as for CLSA analysis was sent for each analysis. These samples were extracted with 30 ml of hexane/15% ether, dried with sodium sulfate, concentrated to 2 ml, and cleaned on a florisil column (5). Two µl were injected splitless onto the column at 170°C, and after 15 minutes, the oven temperature was increased at a rate of 3°C/min from 170°C to 230°C. An internal standard, α,α,α',α'-2,3,5,6-octachloro-p-xylene (Aldrich Chemical Co.) was added for quantification of halogenated compounds. Identification was conducted with similar procedures using GC/MS.

Solvent Extraction with Methylation (SEAM)

After closed-loop-stripping analysis and hexane extraction, the pH of the effluent sample was lowered to 1 or less by the addition of 6N hydrochloric acid. The extraction was performed with four 20-ml volumes of methylene chloride (if emulsions were formed, they were separated by centrifugation). The combined extracts were dried over anhydrous sodium sulfate, filtered through sintered glass and evaporated to a volume of approximately 10 ml in a rotary evaporator at a waterbath temperature of 30°C and a pressure of about 1/2 bar. After transferring the sample to a 10-ml evaporative concentrator tube, it was taken to dryness by the airstream-waterbath method.

Approximately 2.14 g (10 mmoles) of DIAZALD (n-methyl-n-nitroso-p-toluenesulfonamide) was transferred to the 250-ml distilling pot followed by the addition of 30 ml of ethyl ether. As the pot was cooled in an ice waterbath, 10 ml of a 0.71 N aqueous alcoholic KOH solution was added (if a precipitate formed, more 95% EtOH was added until it dissolved), and the flask was allowed to warm to room temperature before the etheral alcoholic diazomethane solution was slowly distilled into the dry-ice-cooled receiving flask. Yield: 320-350 mg or 7.6-8.3 mmoles, or sufficient diazomethane for 4-5 samples.

The residue in the concentrator tube was redissolved in approximately 1 ml of a 50/50 (V/V) ethereal methanol solution. To this reconstituted sample 4 Pasteur pipettes full of ethereal alcoholic diazomethane solution (7 ml) and 1 ml of methanol were added. The solutions were mixed and allowed to sit overnight. When the methylation was complete, the solution was concentrated to a volume of approximately 100 µl by the airstream-

waterbath method, followed by the addition of 100 µl of dry ethyl ether. The solution was mixed well and was then ready for analysis.

For sample analysis, about 4 µl of the extract was injected splitless for 42 seconds onto a 50 m SE 54 column (glass cap. I.D 0.33) at 50°C. After 4 minutes the temperature was raised to 250°C at a rate of 3°C/minute. The final isothermal period was 10 minutes. The column was coupled directly to a Finnigan 4000 mass spectrometer by means of a 1/16-inch glass-lined stainless-steel tube.

Quality Assurance

A number of measures were taken to ensure the consistency and quality of the analytical data. These measures included

- running sample blanks for testing cleanliness of glassware and solvents
- running sample blanks and spiked samples
- analyzing standard mixtures to ensure proper functioning of analytical equipment
- running duplicate samples
- tests with reference compounds
- routine verification of GC peaks.

Analytical Precision

In order to determine the precision of the above analyses, duplicate samples were collected on numerous occasions at WF-21 and sent to Stanford for analysis. Precision of measurement varied with concentration as indicated by the summary in Table 5. The organics listed in this table were selected for routine analysis because they are present on the U.S. Environmental Protection Agency's list of priority pollutants or used as indicators of industrial contamination [6], and were routinely present in measurable concentration in the influent waters to WF-21.

VIRUSES

Virus monitoring was conducted by James M. Montgomery, Consulting Engineers, Inc., Pasadena, California (JMM). The concentration methods used are summarized in Table 6, which includes a brief description of each method, the amount and type of chemical added, the sample volume usually tested, methods of elution, detection limits, the location where the method was used, and the corresponding dates. These methods were developed from a pooling of the information gathered by the San Diego County Health Department; Baylor University; the Los Angeles County Sanitation Districts; the University of California, Berkeley; the University of North Carolina, Chapel Hill; and James M. Montgomery. The various methods were employed in an effort to improve virus recovery and to reduce manpower requirements.

The concentration of enteric viruses in the final concentrated eluate was first determined by the plaque assay method employing either a Buffalo Green Monkey kidney continuous cell line (BGM) maintained at JMM or a

TABLE 5. DETECTION LIMITS AND ANALYTICAL PLUS SAMPLING ERRORS FOR TRACE ORGANIC ANALYSIS

Compound	Detection Limit µg/l	Standard Deviation µg/l**	Applicable Concentration Range µg/l	Number Duplicate Samples Analyzed
Trihalomethanes				
Chloroform	0.1	0.085C+0.25	0.00-10	95
Bromodichloromethane	0.1	0.048C+0.09	0.00-8	114
Dibromochloromethane	0.1	0.064C+0.06	0.00-5	115
Bromoform	0.1	0.18C +0.2	0.00-19	98
Other Volatile Organics				
Methylene chloride	0.1	-	-	-
Carbon tetrachloride	0.1	0.039C+0.05	0.00-1.5	58
1,1,1-Trichloroethane	0.1	0.083C+0.09	0.00-20	95
Trichloroethylene	0.1	0.085C+0.09	0.00-13	83
Tetrachloroethylene	0.1	0.12C +0.05	0.00-8	89
Chlorinated Benzenes				
Chlorobenzene	0.02	0.22C+0.002	0.00-3	21
1,2-Dichlorobenzene	0.02	0.15C+0.029	0.00-14	12
1,3-Dichlorobenzene	0.02	0.44C+0.002	0.00-5	16
1,4-Dichlorobenzene	0.02	0.19C+0.002	0.00-14	12
1,2,4-Trichlorobenzene	0.02	0.28C+0.014	0.00-3	9
Aromatic Hydrocarbons				
Ethylbenzene	0.01	0.94C+0.004	0.00-0.1	18
m-Xylene	0.02	0.87C+0.004	0.00-0.15	18
p-Xylene	0.02	0.87C+0.004	0.00-0.05	9
Naphthalene	0.02	-	-	-
1-Methylnaphthalene	0.02	-	-	-
2-Methylnaphthalene	0.02	-	-	-
SEA Components*				
Dimethylphthalate	0.3	0.42C	0.0 -6	9
Diethylphthalate	0.3	1.1C	0.0 -3	6
Di-n-butylphthalate	0.5	0.83C	0.0 -5	7
Diisobutylphthalate	0.3	0.66C	0.0 -8	10
Bis-[2-ethylhexyl] phthalate	4.0	0.61C	0.0 -17	5
Polychlorinated biphenyls (Arochlor 1242	0.3	0.14C	0.0 -0.6	4
Lindane	0.05	0.09C	0.00-0.15	6

* SEA refers to Solvent Extraction Analysis.
** C is the concentration of the compound in µg/l.

TABLE 6. SUMMARY OF VIRUS CONCENTRATION METHODS

Sampling Meth.	Description	Chemicals Added	Amount	Sample Volume gal	Elution	Eluant Volume ml	Reconcentration Method	Final Eluant Volume ml	Detection Limit PFU/m^3	Location Sampled	Period Used	Cell Assay System
A.	Adsorption on K-27 filter	Al(III) Acid	0.0005M pH 3.5	190	glycine pH 11.5	4000	Flocced, centri-glycine, 3 times, last pellet dissolved and used to plaque.	80	$2x10^2$	Q1	11/25/75 -7/28/76	unconfirmed BGM-PAC Plaques
B.	Direct flocculation	Al(III)	0.003M	3.8	glycine	200	Same as A.	80	10^4	Q4	10/8/76-11/23/76	confirmed BGM
		Al(III)		7.6	pH 11.5	200	Same as A.		$5x10^3$	Q1	12/3/76-6/2/77	Plaque
C.	Direct flocculation	Al(III)		7.6	Nutrient Broth pH 9.0	500	Flocced, centrifuged, eluted twice with nutrient broth, pH 9.0 Coag. at pH 4.3, dissolved at pH 9.0 and plaqued	80	$5x10^3$	Q1	6/20/77 12/31/78	confirmed BGM Plaque
D.	Adsorption on K-27 filter	Al(III) Acid	0.0005M pH 3.5	4200	glycine	8000	Same as A.	80	?	Q2	12/1/75-6/9/76	unconfirmed
										Q3	6/15/76-7/16/76	BGM-PAH Plaque
										Q4	7/20/76-7/29/76	
E.	Adsorption on K-27 and Cox Filter	Al(III) Acid	0.005M pH 3.5	190	glycine pH 11.5	1500	Same as A.	80	$2x10^2$	Q9	10/8/76-6/2/77	confirmed BGM-RMK Plaques
F.	Adsorption on K-27 and Cox Filter	Al(III) Acid	0.0005M pH 3.5	190	Nutrient Broth pH 9.0	1500	Same as C	80	$2x10^2$	Q9	6/20/77-12/31/78	confirmed BGM-RMK Plaques

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TABLE 6. (CONTINUED)

Sampling Meth.	Description	Chemicals Added	Amount	Sample Volume gal	Elution	Eluant Volume ml	Reconcentration Method	Final Eluant Volume ml	Detection Limit PFU/m^3	Location Sampled	Period Used	Cell Assay System
G.	Adsorption on Filterite Filter	Al(III) Acid	0.0005M pH 3.5	38	Beef Extract pH 9.0	1000	Same as C.	80	10^3	01	5/17/78-6/6/78	
		"	"	76	"	"	"	"	500	01	7/17/78-7/27/78	confirmed BGM
		"	"	190	"	"	"	"	200	01	8/2/78 present	plaque, Liquid
		"	"	950	"	"	"	"	40	0-22A	5/17/78-6/6/78	BGM & RD
		"	"	1900	"	"	"	"	20	0-22B	5/17/78-6/6/78	
		"	"	950	"	"	"	"	40	09	7/17/78-present	
H.	Adsorption on Zeta Plus	--	--	76 2	Beef Extract pH 9.0	1000	Same as C.	80	10^3	01	In progress	

Primary African Green Monkey kidney (PAG) cell line purchased commercially. The general method consisted of adding Earle's Balanced Salts, Fetal Calf Serum (FCS), and antibiotics to the sample, incubating at 37°C for 90 min, diluting with 0.05M Tris Buffer, inoculating a 30- or 60-ml prescription bottle containing the attached cell line, incubating for 90 min at 37°C (absorption), washing the cells with Phosphate Buffered Saline (PBS), overlaying them with agar, and incubating at 37°C. Plaques were counted on days 2 through 7.

During the course of this study it was found that many of the apparent plaques were not caused by animal viruses, and hence confirmation of plaques was required in order to obtain a time count. For confirmation, cellular debris from all suspected plaques were passed to tubes containing a monolayer of BGM cells and maintenance media, placed on a roller apparatus, and incubated for 7 to 8 days. A small sample was then passed to a new tube of the same kind and these tubes were examined for cytopathic effects during 2 to 7 days incubation. The positives were then recorded as confirmed plaques. Tubes determined as positive were then frozen at -70°C. All Q9 positives were identified as were a small percentage of the positive Q1 samples by JMM. In addition, identifications were made by the California Department of Public Health (CDPH), using a greater variety of cell lines in order to obtain a broader range of identifications. The CDPH was involved directly for several months initially to help select cell lines most useful for monitoring reclaimed wastewaters, and have continued to oversee and review the virus monitoring efforts.

Virus identifications by JMM were accomplished using the Lim-Belnish-Melnick cross-secting antisera. A microtiter system using a cytopathic effect (CPE) as a positive response was employed in some identifications and a plaque reduction method was employed for others. After an initial titering of the isolated virus, it is appropriately diluted to 100 $TCID_{50}$/0.1 ml mixed with the cross-secting antisera, incubated one hour at room temperature, and inoculated into microtiter dishes or plaquing bottles. Neutralization of the CPE from a plus four to a plus one or an 80% reduction of plaques is the criteria used for identification.

Later during the study it was determined that BGM liquid culture and the human RD cell line (RD) provided a broader range of sensitivity to the enteric virus found in secondary effluent. For a short period rhesus monkey kedney cells (RMK) were also tested. Procedures were changed to these two cell lines. A BGM liquid culture was inoculated with a small sample volume (0.2 ml). If toxicity occured, an observable effect was noted within 24 to 48 hours. Toxic samples were either diluted or extracted with dithizone in chloroform to remove the toxicity. The screened and detoxified samples were then inoculated into BGM and RD liquid cultures. Two tubes per type were inoculated with 0.25 ml of sample. Fetal calf serum and an antibiotic, kanamycin, were added to reduce toxicity and microbial contamination. The samples were allowed to adsorb for 1 hour before 2 ml of maintenance media per tube was added. The tubes were then rolled for 7 to 14 days and periodically checked for cytopathic effects. The negative tubes were then discarded and the remainder were transferred to other tubes for confirmation.

In this procedure the most probable number of cytopathogenic units (MPNCU) was calculated with the formula

$$MPNCU = -\ln(S/N)/V \qquad (5\text{-}1)$$

where

MPNCU = most probable number of cytopathic units per ml of concentrate

V = ml of concentrate inoculated per tube

S = number of negative tubes

N = number of tubes inoculated

In order to convert the MPNCU for the concentrate to the MPNCU for the water being tested, the value from Eq. 5-1 was multiplied by the ratio of the total volume of concentrate collected to the total sample volume of water used.

The plaque counting technique results in reported values of PFU per liter while the liquid culture technique leads to reported values in MPNCU per liter. It is hoped that these different methods of reporting results do not cause too much confusion to the reader.

SECTION 6

DATA ANALYSIS

SELECTION OF DISTRIBUTION MODEL

The characteristics of the influent and effluent waters, and the performance of Water Factory 21, vary from day to day. In order to interpret the data obtained from monitoring, a model which adequately describes the probability distribution of each organic contaminant and each location in the treatment system was sought. Several probability models were considered, parameters for each were evaluated using various sets of organic and inorganic concentration data from Water Factory 21, and the results of model predictions were compared to determine which model most consistently provided good statistical correlation with the data. Models for normal and lognormal probability distributions [7] received most consideration since they gave reasonable fits to much of the data and also readily lent themselves to statistical interpretation.

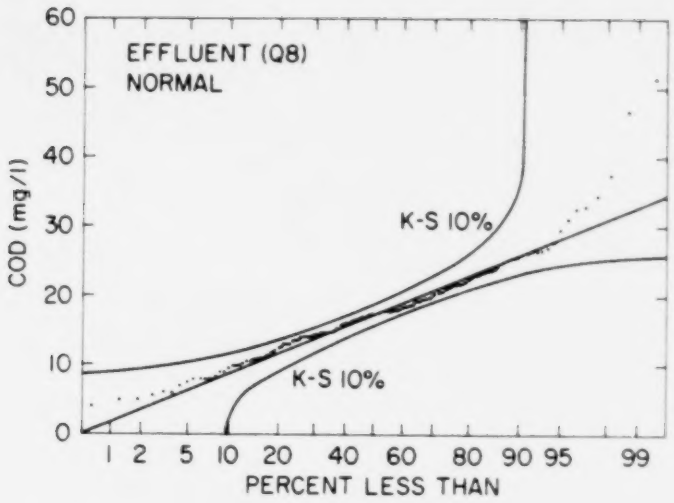
Dean [8] indicated that concentrations of constituents in untreated and treated wastewaters generally follow a lognormal rather than normal distribution. He suggested that the lognormal distribution has a strong theoretical justification based on the concept that fluctuations are proportional rather than additive. From these considerations, a lognormal distribution was expected to be an appropriate model for the data. Nevertheless, it was felt that verification was desirable since no other extensive analysis for such a wide range of trace substances in wastewater was presently available.

A graphical approach using the Kolmogorov-Smirnov test (K-S) test [7] was selected for initial screening of possible models (Figure 5). Data were arranged in descending rank order and the probability distribution F* for each measured concentration was determined from [9]:

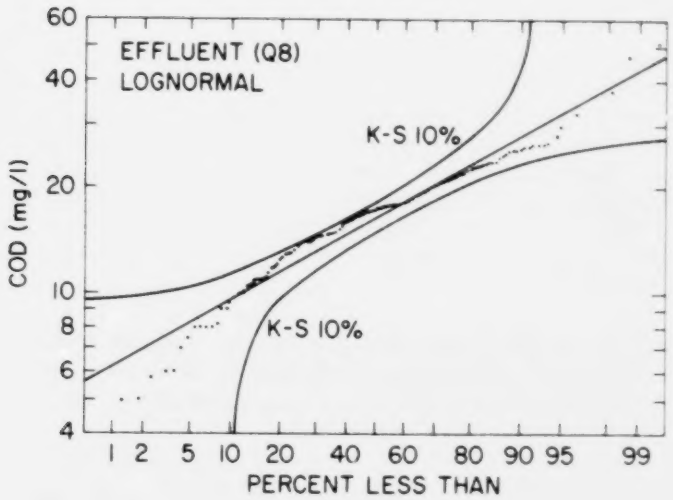
$$F^*(X^{(i)}) = \frac{i - 3/8}{N + 1/4} \qquad (6\text{-}1)$$

Where $X^{(i)}$ is the i^{th}-largest observed value in the random sample of size N. Equation 6-1 rather than $F^*(X^{(i)}) = i/N$ was used in the K-S test in order to avoid problems with endpoints.

Normally distributed data will plot as a straight line on probability paper if the ordinate scale is arithmetic, while lognormally distributed data will plot as a straight line if the ordinate scale is logarithmetic. The K-S test allows a statistical determination of how much deviation from



5a. Effluent (Q8) - normal distribution.



5b. Effluent (Q8) - lognormal distribution.

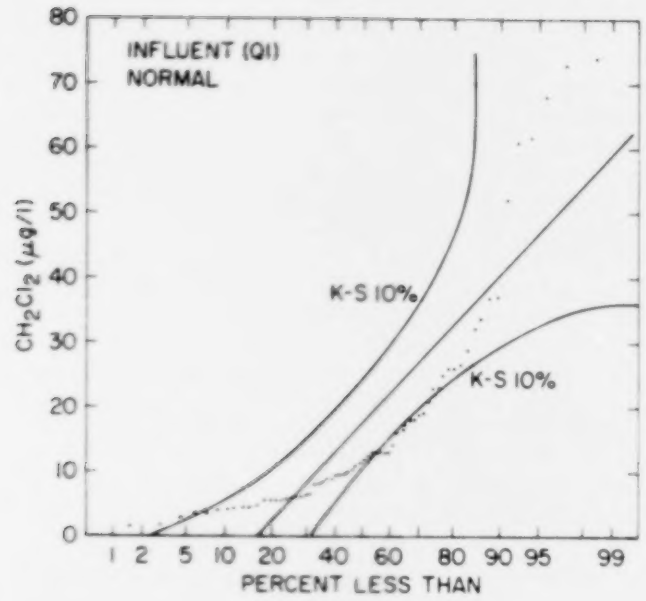
Figure 5. Comparison between normal and lognormal probability distributions for effluent COD data during the third period.

the straight line is acceptable. Curves are drawn above and below the data line to represent boundaries beyond which no data in the distribution should cross, except with low probability, if the model is an adequate description of the data distribution. The curves shown in Figure 5 represent those for 10-percent significance, which was the level used in this evaluation. A model is rejected in this screening test if the data at any point pass over the K-S boundary. In Figure 5 both the normal and lognormal distributions of Q8 COD data fit within these boundaries and so neither model can be rejected at the 10-percent significance level. For this set of data, also, the normal distribution seems to be a better fit in the middle portion of the distribution, but lognormal is better for the upper tail. Thus, there is no obvious choice here between the two models.

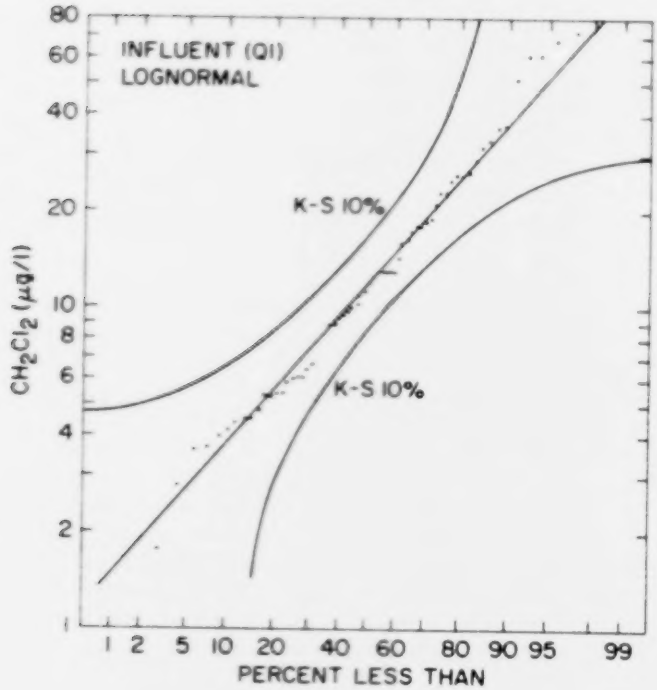
An example of a clear choice between models is illustrated in Figure 6 for methylene chloride. The lognormal distribution fits the data exceptionally well, while the normal distribution can be rejected at the 10-percent significance level. Probability plots with K-S limits for the trace organic data in general were prepared by computer graphics. An example is given in Figure 7 for 1,3-dichlorobenzene. The abscissa coordinates here represent a normalization of the percent probability coordinates. One on the scale represents one standard deviation from the mean.

Computer plots for models which could not be rejected by the initial screening were examined visually to determine whether one model provided an obvious better fit over the other. A comparison was made between plotted and predicted values near the 50-percent and 90-percent less than values. If one model provided an obvious better fit visually and a check at the midpoint and upper limits confirmed the visual test, then that model was selected over the other. A summary of the results of this analysis is given in Table 7, and more specific details are contained in Appendix G.

Distributions for 186 sets of trace organics data from 12 different sampling locations and for periods two and three were examined. Distributions for 156 sets of data for general parameters and inorganics at nine sampling locations for the same periods were also examined. The lognormal distribution was found best for 47-percent of the distributions, normal for 8-percent of the distributions and both models fit the data well for 39-percent of the distributions. In 22-percent of the cases the normal distribution was rejected by the K-S test, but the lognormal distribution was rejected in only 8% of the cases. Six percent of the latter were from distributions for only two parameters, ammonia and electroconductivity. It was concluded that the lognormal distribution adequately represented the results at least 92-percent of the time and thus provided an adequate description of the probability for organic and inorganic materials at Water Factory 21.



6a. Influent (Q1)-normal distribution.



6b. Influent (Q1)-lognormal distribution.

Figure 6. Comparison between normal and lognormal distributions for influent methylene chloride.

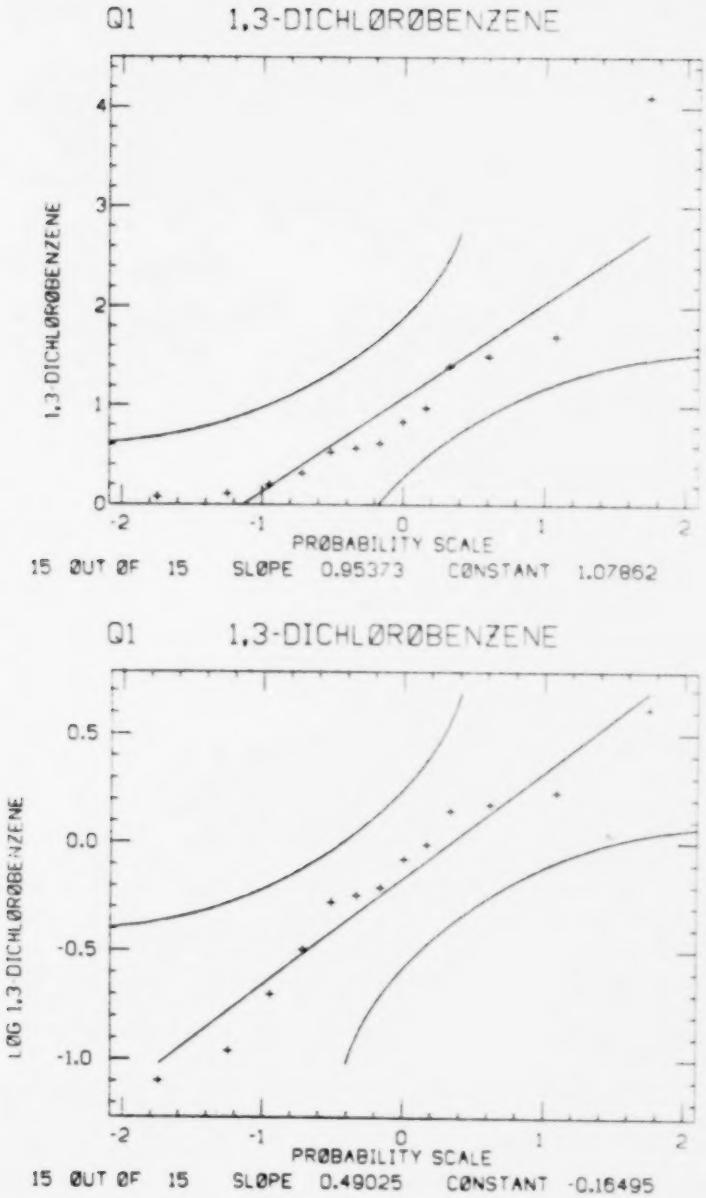


Figure 7. Computer plots showing comparison between normal (upper) and lognormal distributions for 1,3-dichlorobenzene (µg/l) during Period Two in Water Factory 21 influent (Q1).

TABLE 7. SUMMARY OF COMPARISON BETWEEN NORMAL AND LOGNORMAL DISTRIBUTIONS FOR ORGANIC, INORGANIC, AND GENERAL PARAMETER DATA

Best Fit Model		Fit Within K-S Boundries		Number of Distributions		
Normal	Log-normal	Normal	Log-normal	Organic	Inorganic and General	Totals
Both		Both		90	45	135
	X	X	X	65	37	102
	X		X	17	41	58
X		X	X	12	8	20
X		X		2	7	9
Neither		Neither		0	18	18
			Totals	186	156	342

CHARACTERISTICS OF THE LOGNORMAL DISTRIBUTION

Dean [8] presented procedures for interpretation of data which follow a lognormal distribution, and has described the usefulness of the model for evaluation of plant reliability. In order to analyze a set of data, logs of each datum are taken and the average and standard deviation of the logs are determined by common statistical procedures. The antilog of the mean so obtained represents the geometric mean, M, and the antilog of the standard deviation gives the spread factor, S. For a lognormal distribution 68.3 percent of the data will lie between concentrations represented by M/S and MS, and 95.5 percent of the data will lie between M/S^2 and MS^2. The relationships between M, S, and the distribution of concentrations for the case when M = 10 and S varies between 1 and 10 is illustrated in Figure 8.

For many trace constituents, concentrations were frequently below the detection limit and an approach was needed which would not lose the value of this information. For this case, the total number of analyses, N, which includes those below the detection limit, were used to determine $F^*(X^{(i)})$, but only the values above the detection limit were plotted on log probability paper. The total number of data points at or above the detection limit is recorded as Nu. A straight line using least-squares was fitted to the data. The antilog of the zero intercept of this line represents M, and the antilog of the slope of the line is equal to S. Data were always displayed graphically by computer plots so that possible errors from using this approach might become apparent (Figure 9).

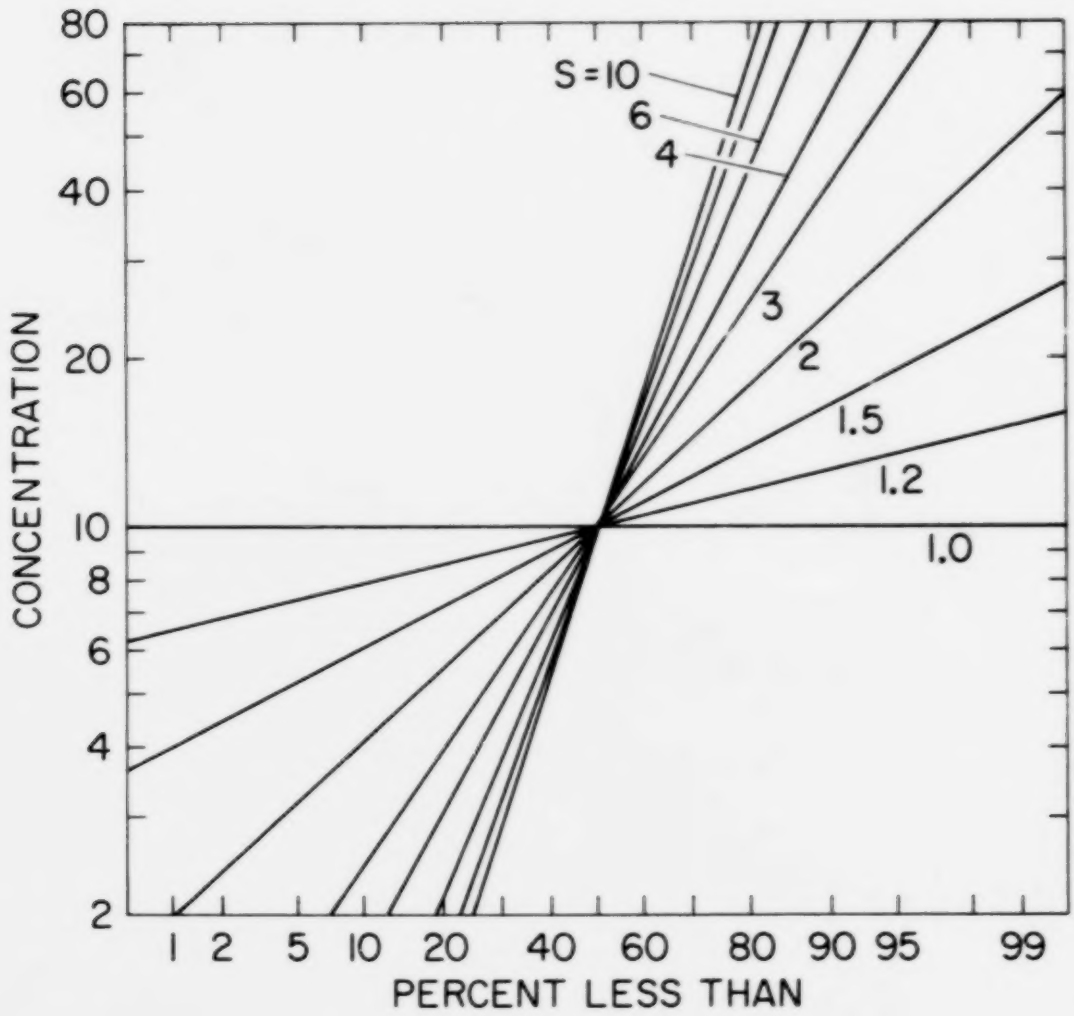


Figure 8. Probability distribution of concentration as a function of S when M equals 10.

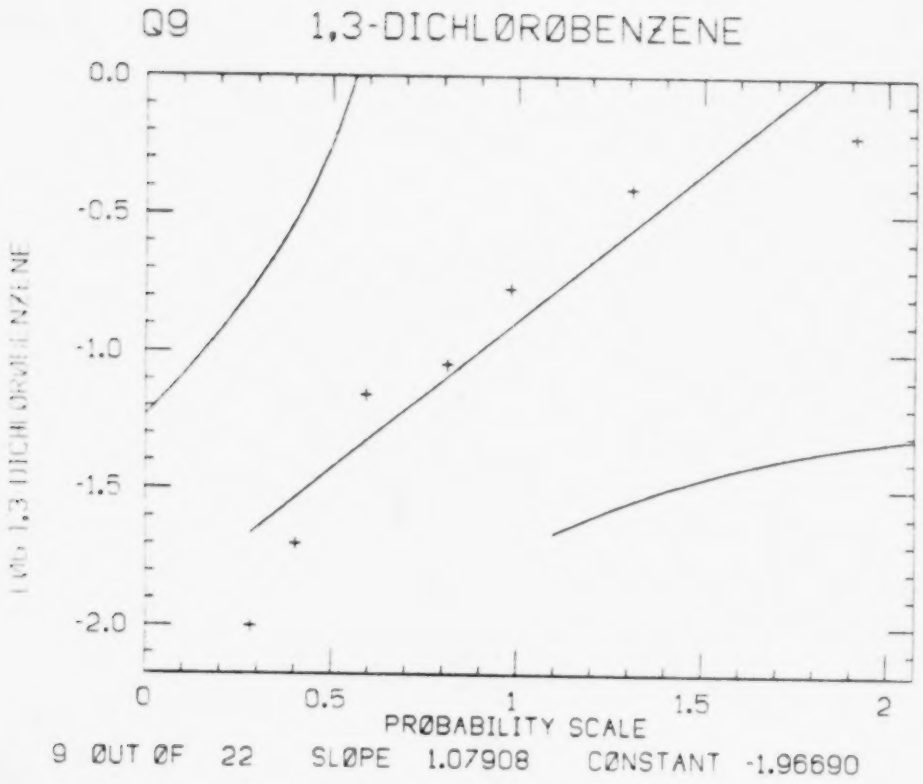


Figure 9. Computer plot of lognormal probability for case where only 9 out of 22 values were above the detection limit. Line is least-squares fit to the 9 data points. Data is in µg/l for Period Two for 1,3-dichlorobenzene in Water Factory 21 effluent (Q9).

In order to give a better indication of the uncertainty in calculated M values, the 95-percent confidence interval (CI) was determined by

$$95\%\ CI = MS^{\pm(t/\sqrt{N_u})} \qquad (6\text{-}2)$$

where t is the value from a t-distribution table for a two-tailed 0.95 point with $N_u - 1$ degrees of freedom.

At times it was desirable to determine the efficiency of a given process or of a combination of processes. This was generally computed as follows:

$$\%\ \text{Removal Efficiency} = 100\ (Mi-Me)/Mi \qquad (6\text{-}3)$$

where Mi and Me are the geometric mean influent and effluent concentrations, respectively, for the process or combination of processes. The 95% confidence interval for the average removal efficiency was determined from:

$$95\%\ CI = 100\ [1 - \frac{Me}{Mi}\ (10^{\pm ts_r})] \qquad (6\text{-}4)$$

in which,

$$s_r = [(\log S_i)^2/Nu_i + (\log S_e)^2/Nu_e]^{1/2} \qquad (6\text{-}5)$$

and t is based upon a two-tailed 0.05 level of significance with $Nu_i + Nu_e - 1$ degrees of freedom. The confidence interval for percent removal provides a measure of the adequacy of the data for drawing firm conclusions about removal efficiency.

In summary, the lognormal distribution was used for analysis of data obtained from Water Factory 21. A summary of the data for a given compound or parameter at a given sampling location over a given interval is represented by the geometric mean, M, spread factor, S, 95-percent confidence interval of the mean, 95% CI, the total number of data points, N, the number of data points above the analytical detection limit, Nu, and the range of data, R, which includes the lowest and highest measured values among the N data. This statistical analysis can provide the information needed to make decisions concerning the reliability of Water Factory 21 to meet given standards, and allows an evaluation of the overall performance of the treatment system.

SECTION 7

OVERALL PLANT PERFORMANCE

GENERAL SUMMARY

Tables 8 and 9 indicate the influent and effluent concentrations for general organics as measured by COD and TOC, turbidity, electroconductivity (EC), coliforms, and other general contaminants for WF-21 during the second and third periods. Detailed information on confidence intervals, spread factors, and sample numbers is contained in the appendices. A comparison of changes in influent concentrations between the two periods indicates a general reduction in most contaminants occurred following the changeover to activated sludge treated water with reduced industrial contribution. Only the concentrations of inorganic constituents represented by EC, boron and fluoride changed little between the two periods. Also indicated in the tables is the change in concentration which resulted from advanced treatment through activated carbon (Q8 or Q9 samples) during the two periods, and in COD, TDS, EC, and nitrate by reverse osmosis during the third period.

The quality of the blended water prior to injection is also indicated in these tables. During the second period, the blended water consisted primarily of a mixture of AWT effluent and deep well water. The objective of blending was to reduce the EC below 900 µS/cm as required by State and Regional authorities. During the third period, the blended water was primarily a mixture of AWT and RO effluents, although some deep water was also mixed in. The COD of the blended water for injection was generally below 10 mg/l.

ORGANICS REMOVAL AND FORMATION OF CHLORINATION PRODUCTS

Detailed Characterization

Water Factory 21 influent (Q1) and effluent samples (Q8, Q9 or Q22B) were analyzed for specific compounds with the procedures detailed in Section 5. The compounds identified are listed in Table 10. They are classified as aromatic hydrocarbons, synthetic chlorinated compounds, chlorination products, natural products, phthalate esters, and miscellaneous compounds. Also indicated by underlining are the particular compounds which are contained on the EPA list of priority pollutants. Compounds from Table 10 which were in sufficiently high concentration and measurable by the routine procedures of VOA, CLSA, and SEA were measured on a routine basis. The results of these analyses are summarized in the Appendices.

TABLE 8. GEOMETRIC MEAN INFLUENT AND EFFLUENT CONCENTRATIONS FOR GENERAL CONTAMINANTS DURING SECOND PERIOD

Contaminant	Influent Q1	AWT Eff. Q8 or Q9	Blended Effluent Q10
COD, mg/l	141	17	9.6
TOC, mg/l	30	7	
TDS, mg/l	1,012	892	413
EC, µS/cm	1,730	1,330	708
Coliforms, MPN/100ml			
Total	89×10^6	0.01	0.03
Fecal	25×10^6	<1	<1
Turbidity, TU	42		0.4
Organic-N, mg/l	7.4	1.1	0.4
Ammonia-N, mg/l	30	2.0	0.6
Nitrate-N, mg/l	0.23	0.4	0.4
B, mg/l	0.94	0.59	0.33
F, mg/l	1.4	0.6	0.6

TABLE 9. GEOMETRIC MEAN INFLUENT AND EFFLUENT CONCENTRATIONS FOR GENERAL CONTAMINANTS DURING THIRD PERIOD

Contaminant	Influent Q1	AWT Eff. Q8 or Q9	RO Eff. Q22B	Blended Water Q10
COD, mg/l	47	12	1.3	6.0
TOC, mg/l	12.4	6.2		
TDS, mg/l	902	849	77	280
EC, µS/cm	1,500	1,320	156	500
Coliforms, MPN/100ml				
Total	1.6×10^6	0.05		0.01
Fecal	0.55×10^6	<1		<1
Turbidity, TU	6.5			0.28
Organic-N, mg/l	2.0	1.1		0.43
Ammonia-N, mg/l	4.0	0.8		0.3
Nitrate-N, mg/l	2.8	7.7	3.3	2.5
B, mg/l	0.74	0.53		0.38
F, mg/l	1.3	0.81		0.57

TABLE 10

COMPOUNDS IDENTIFIED IN WF-21 INFLUENT (Q1) AND EFFLUENT (Q9 AND Q22B)

Aromatic Hydrocarbons

benzene
[e]toluene
[e]ethylbenzene
[e]p-xylene
[e]m-xylene
[e]o-xylene
[e]1-ethyl-4-methylbenzene
[e]1-ethyl-3-methylbenzene
[e]1,3,5-trimethylbenzene
[e]1-ethyl-2-methylbenzene
[e]1,2,4-trimethylbenzene
[e]1,2,3-trimethylbenzene
C_4-benzenes
indane
methylindanes
[e]naphthalene
[e]1-methylnaphthalene
[e]2-methylnaphthalene
C_2-napthalenes
C_3-naphthalenes
styrene
biphenyl
phenanthrene/anthracene
[e]methylphenanthrene (4 isomers)
phenylnonane isomers
phenylundecane isomers
C_3-biphenyl isomers
C_6-biphenyl isomers
pyrene/fluoranthene

Synthetic Chlorinated Compounds

[e]methylene chloride
[e]trichloroethylene
[e]tetrachloroethylene
[e]1,1,1-trichloroethane
[e]1,1,2-trichloroethane
[e]hexachloroethane
[e]chlorobenzene
[e]1,2-dichlorobenzene
[e]1,3-dichlorobenzene
[e]1,4-dichlorobenzene
[e]1,3,5-trichlorobenzene
[e]1,2,4-trichlorobenzene
[e]PCB Aroclor 1242
pentachlorophenylmethylether
tetrachlorophenylmethylether isomers
trichlorophenylmethylether isomers
dichlorophenylmethylether isomers
[e]carbon tetrachloride
lindane
tetrachlorobenzene isomer

Chlorination Products

[e]chloroform
[e]dichlorobromomethane
[e]chlorodibromomethane
[e]bromoform
[e]dichloroiodomethane
[e]1,1,2,2-tetrachloroethane
[e]β-chlorostyrene isomers
[e]chlorobromoiodomethane
[e]1,1,1-trichloroacetone
[e]chloroxylene
[e]chlorobromopentanone
[e]bromoketone
[e]methylchlorobenzene
[e]α,β-dichloroethyl benzene

(continued)

TABLE 10 (Continued)

Natural Products

terpenes
terpene alcohols
fenchone
fenchyl alcohol
trans-beta-farnesane
heptaldehyde
*lauric acid methyl ester
*myristic acid methyl ester
*peritadecanoic acid methyl ester isomers
*heptadecanoic acid methyl ester
stearic acid methyl ester
palmitic acid methyl ester

Phthalate Esters

[e]dimethylphthalate
diethylphthalate
[e]di-n-butylphthalate
[e]di-isobutylphthalate
[e]bis(2-ethylhexyl)phthalate

Miscellaneous Compounds

camphor
isophorone
p-t-amylphenol
octylcyanide
hexylcyanide
other alkylcyanide
[e]methyl-2-(p-chloro-phenoxy)-2-methyl-propionate
o-isomer clofibrate metabolite
methylbenzoate
[e]tolualdehyde isomers
ethylphenol
2-chloropyridine
[e]benzaldehyde
[e]pentadecane
[e]octadecane
[e]acetophenone

#Priority pollutants are underlined

[e]Found in effluents

*Identified after methylation

COD Removal

Figures 10 and 11 illustrate the distribution of COD at various sampling locations at Water Factory 21 during the second and third periods, respectively. The 50-percent point on each line represents the geometric mean concentration, M, and the slope of the line is equal to the spread factor, S, as described in Section 6. The geometric mean influent concentration of COD decreased significantly from 141 mg/l during the second period to 47 mg/l during the third period. Lime treatment, filtration,

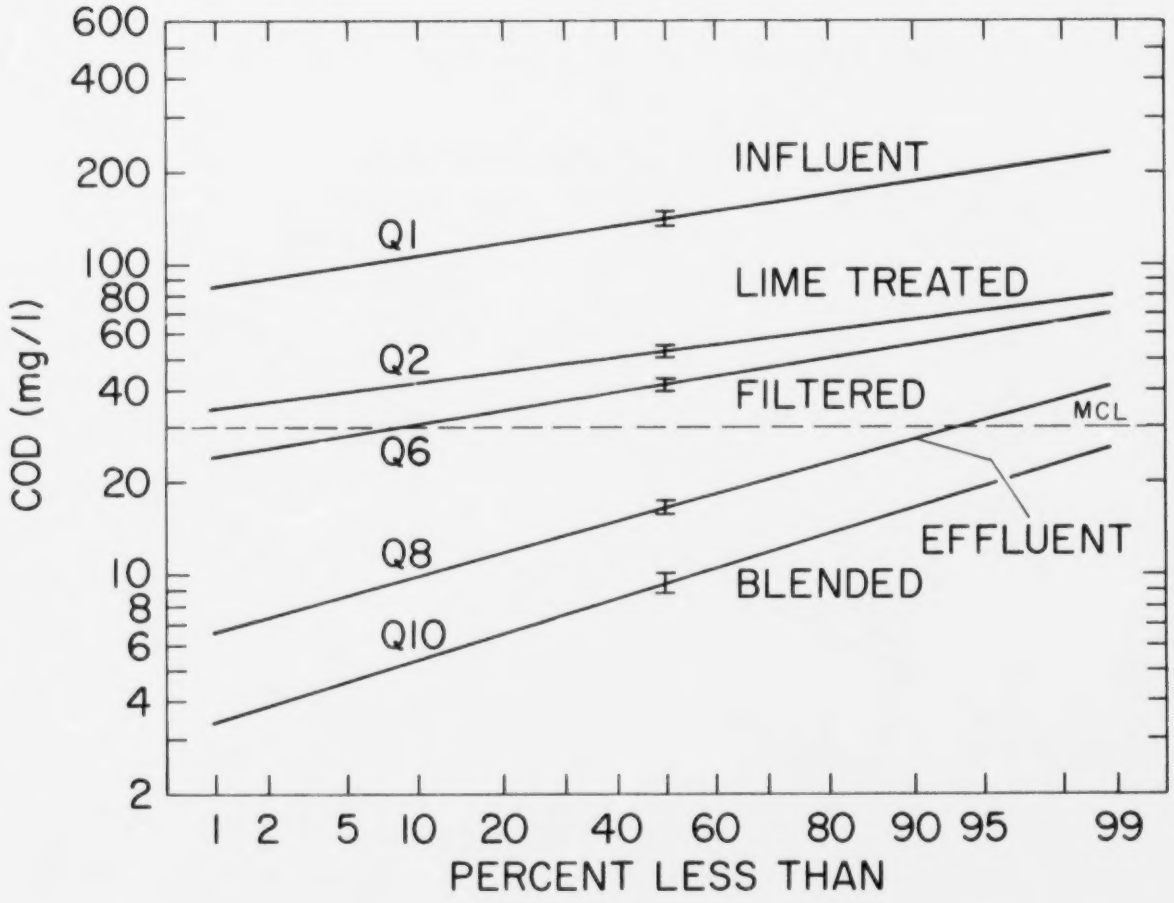


Figure 10. Distribution of COD at various Water Factory 21 sampling locations during second period (October 1976 through February 1978).

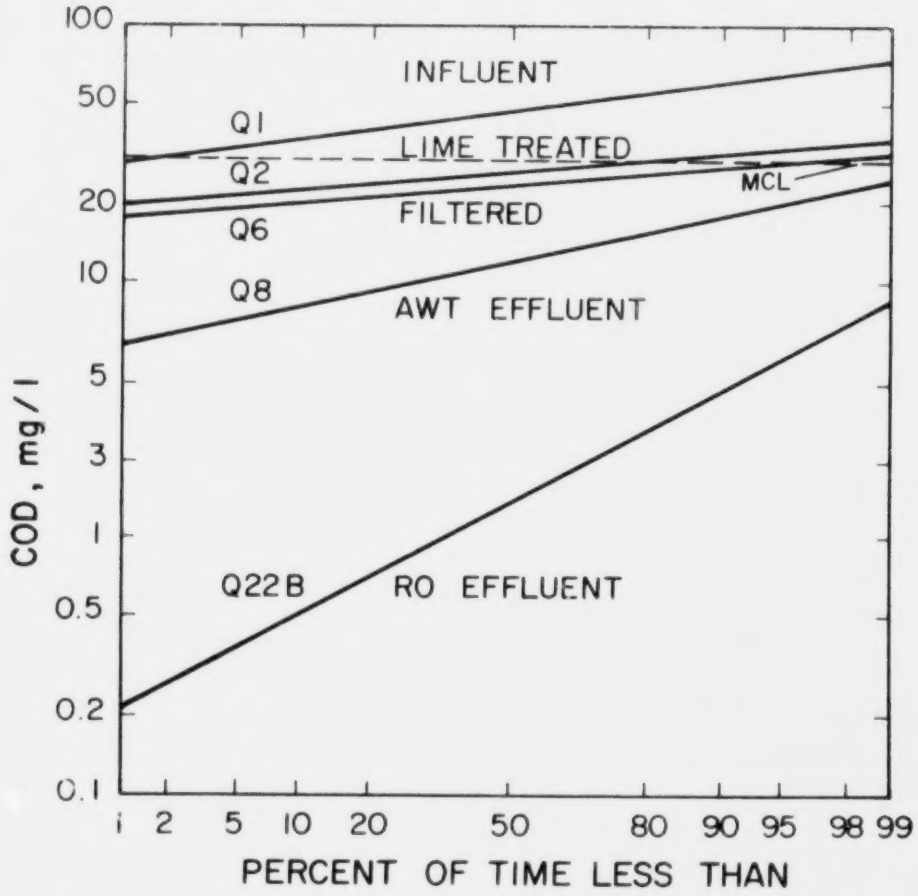


Figure 11. Distribution of COD at various Water Factory 21 sampling locations during third period (March 1978 through December 1978).

and carbon adsorption, and reverse osmosis all resulted in significant decreases in COD. The regulatory requirement for COD after carbon adsorption (Q8) for daily composite samples is less than 30 mg/l. Based upon the distribution shown, this requirement was met 92 percent of the time during period two and more than 99 percent of the time during period three. The spread factor as reflected by an increased slope of the distribution lines increased with decrease in COD through the reclamation plant, and was due in large measure to an increased contribution of analytical error to the overall concentration variance as COD approached the detection limit of about 1 mg/l.

Trihalomethanes

The effects of breakpoint chlorination on trihalomethane concentrations in the effluent is illustrated by a comparison of the two graphs in Figure 12. Thiosulfate was added to the sample bottle prior to sample collection to reduce residual chlorine, and thus prevent further trihalomethane formation beyond that resulting from about two hours of residence time in the final chlorine contact tank. Even following breakpoint chlorination for ammonia removal the sum of the effluent trihalomethane concentrations was well below the EPA-proposed (1978)[6] 100 µg/l level for drinking waters in more than 99 percent of the samples taken. The relatively low concentration is partly a result of precursor removal by treatment and partly because breakpoint chlorination was not complete and a large portion of the residual chlorine was present as chloramines. Chloramines are not as effective as free chlorine in trihalomethane formation (10).

Trace Organics Removal

Over 25 trace organic materials were in sufficient concentration so that their distribution could be well quantified and the efficiency of removal by treatment could be measured. The influent and effluent concentration distributions for some of these materials are summarized in Figures 13 through 16. A comparison of the influent and effluent concentrations in Figure 13 indicates the chlorobenzenes were removed effectively by treatment. Figure 14 indicates that the trihalomethane concentrations generally increased during treatment, as a net result of removal through some processes and formation by chlorination in others as already indicated. Figure 15 shows that the aromatic hydrocarbon concentrations were relatively low in the influent and were only partially removed by treatment.

Figure 16 shows that several chlorinated methane and ethane compounds were relatively high in concentration in the influent waters, and treatment produced varying results. The concentration of carbon tetrachloride, CCl_4, increased slightly during treatment. It was probably added as a contaminant in chlorine. On the average, CCl_3CH_3 was removed well by treatment, although for a small percentage of the time the effluent concentration was quite high. Similar results were obtained with CCl_2CHCl, although in this case the high values all occurred during one short period. This may have been an analytical artifact, and this is being explored. Finally, overall CCl_2CCl_2 removal was relatively poor. In this case, the processes through activated carbon treatment removed this compound well, but it subsequently increased

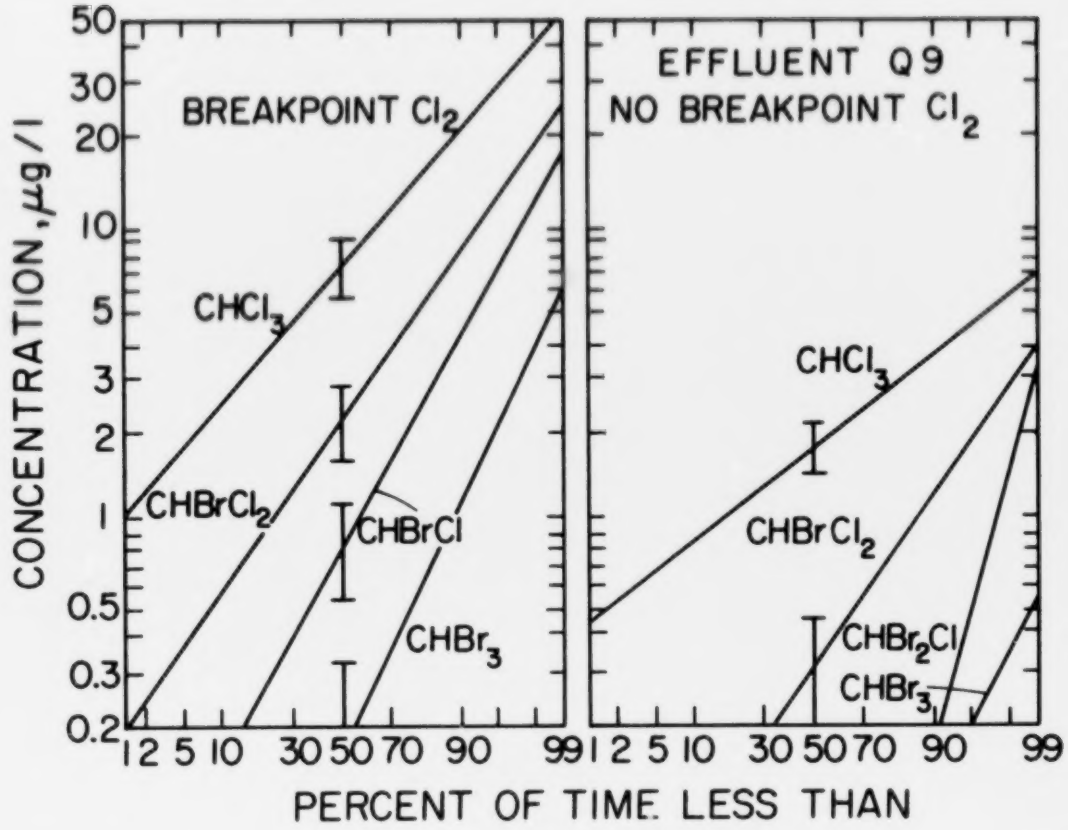


Figure 12. Trihalomethane distribution and 95% confidence interval for the geometric mean in the effluent (Q9) before and after breakpoint chlorination was instigated (Periods 1 and 2).

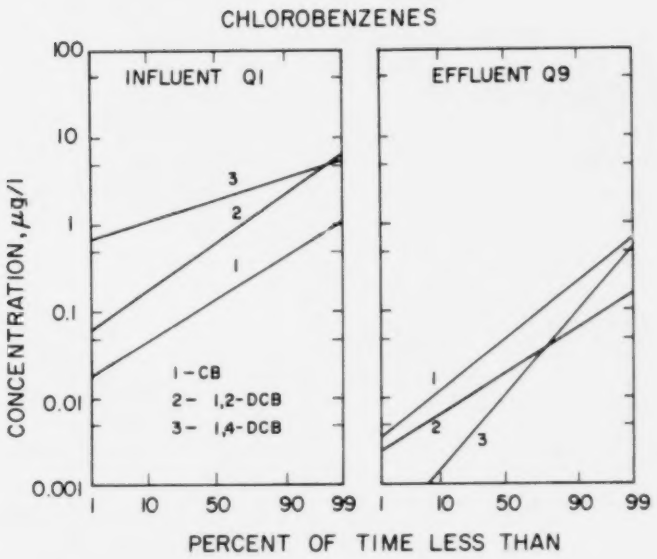


Figure 13. Distribution of chlorobenzene concentrations in the influent and effluent during third period. Curves shown are for chlorobenzene (CB), 1,2-dichlorobenzene (1,2-DCB), and 1,4-dichlorobenzene (1,4-DCB).

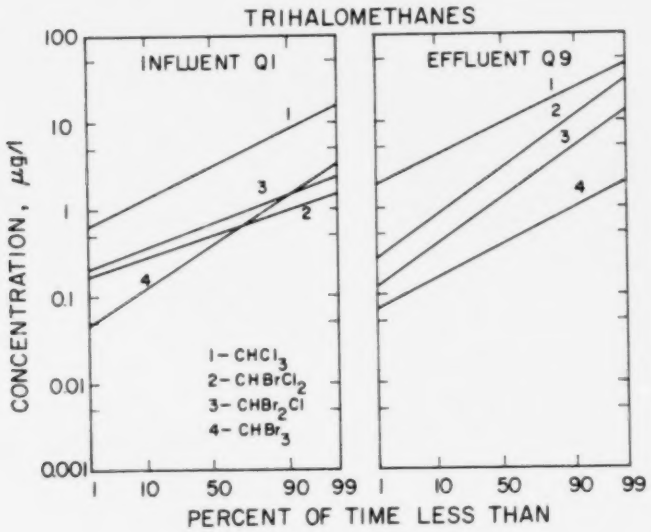


Figure 14. Distribution of trihalomethane concentrations in the influent and effluent during third period.

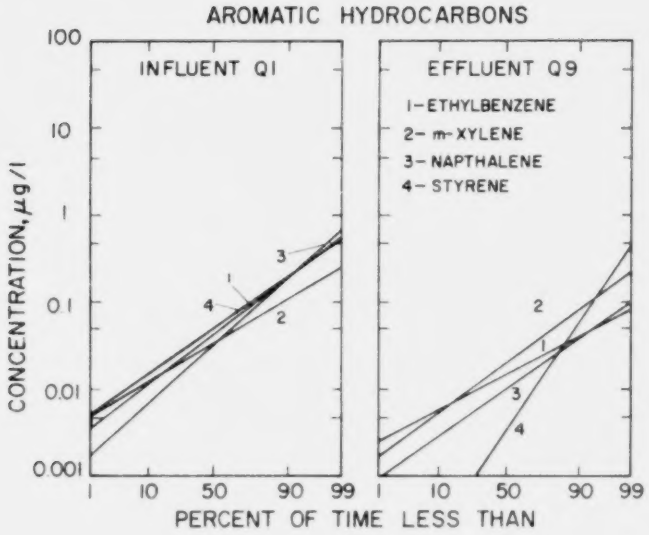


Figure 15. Distribution of aromatic hydrocarbons in the influent and effluent during the third period.

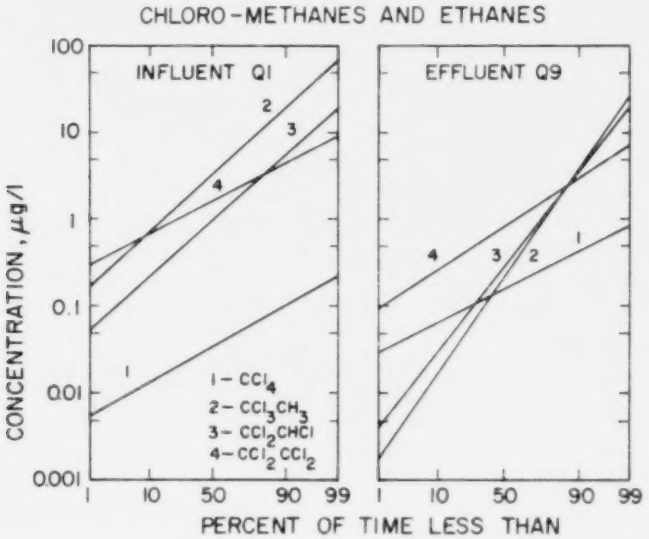


Figure 16. Distribution of various chlorinated methanes and ethanes in the influent and effluent during third period.

in concentration through the final chlorine contact basin. This occurred during the third period only after the basin was coated with a CCl_2CCl_2 containing coal-tar epoxy in order to reduce concrete corrosion from low pH due to chlorination.

The average removal efficiency for the various organic materials which were routinely quantified, and the 95% confidence interval for the average removal was determined as outlined in Section 6 using the detailed summary data in the appendices. Results together with geometric mean influent concentrations are given in Tables 11 and 12 for periods two and three respectively.

TABLE 11. REMOVALS OF ORGANIC SUBSTANCES THROUGH AWT TREATMENT DURING SECOND PERIOD

Contaminant	Inf. Conc.* (Q1)	Eff. Conc.* (Q9)	Percentage Removal	
			Average	95% Confidence Inter. for Aver.
COD	141	17	88.2	87.6 to 88.8
Methylene chloride	17	1.6	90.6	85 to 94
1,1,1-Trichloroethane	4.7	0.07	98.5	97 to 99
Trichloroethylene	0.9	0.02	97.8	91 to 99
Tetrachloroethylene	0.6	0.05	91.7	67 to 98
Chlorobenzene	2.5	0.05	98.0	96 to 99
1,2-Dichlorobenzene	2.4	0.03	98.8	96 to 100
1,3-Dichlorobenzene	0.68	0.01	98.5	91 to 100
1,4-Dichlorobenzene	2.1	0.02	99.0	94 to 100
1,2,4-Trichlorobenzene	0.46	0.01	97.8	86 to 100
Ethylbenzene	1.4	0.03	97.9	96 to 99
Naphthalene	0.57	0.03	94.7	90 to 97
1-Methylnaphthalene	0.86	0.04	95.3	91 to 97
2-Methylnaphthalene	1.0	0.02	98.0	92 to 99
Dimethylphthalate	16	1.7	89.4	69 to 96
Diisobutylphthalate	2.9	0.74	40.0	0 to 94
Bis-[2-ethylhexyl]phthalate	28	3.2	88.6	60 to 97
PCBs measured as Aroclor 1242	3.3	<0.3	> 91	-

*µg/l except COD which is in mg/l

TABLE 12. REMOVALS OF ORGANIC SUBSTANCES THROUGH AWT TREATMENT DURING THIRD PERIOD

Contaminant	Infl. Conc. (Q1)	Eff. Conc.* (Q9)	Percentage Removal	
			Average	95% Confidence Inter. for Aver.
COD	47	12	73.8	72.2 to 75.4
1,1,1-Trichloroethane	3.25	0.20	94	83 to 98
Trichloroethylene	0.74	<0.1	>86	-
Tetrachloroethylene	1.67	0.83	50	22 to 68
Chlorobenzene	0.14	0.05	65	40 to 80
1,2-Dichlorobenzene	0.64	0.02	97	93 to 99
1,3-Dichlorobenzene	0.16		>97	-
1,4-Dichlorobenzene	1.9	0.012	99.4	98.2 to 99.8
1,2,4-Trichlorobenzene	0.11		>99	-
Heptaldehyde	0.10	0.03	71	-5 to 92
Ethylbenzene	0.043	0.014	67	41 to 82
m-Xylene	0.035	0.02	43	-9 to 70
p-Xylene	0.015	0.012	20	-45 to 56
Naphthalene	0.033	0.01	70	0 to 91
1-Methylnaphthalene	0.008	<0.02	?	-
2-Methylnaphthalene	0.01	<0.02	?	-
Styrene	0.048	0.003	94	45 to 99
Dimethylphthalate	4.8	0.47	90	81 to 95
Di-n-butylphthalate	0.79	0.33	58	7 to 81
Diisobutylphthalate	4.7	0.27	94	84 to 98
Bis-[2-ethylhexy]phthalate	11	3.1	72	60 to 80
Polychlorinated biphenyls measured as Aroclor 1242	0.47	<0.3	>36	-
Lindane	0.14	<0.05	>67	-

*µg/l except COD which is in mg/l and was measured at location Q8.

The confidence intervals for average percent removals for the second period (Table 11) are generally quite small and in general indicate overall removals of 90 percent or better. Diisobutylphthalate is one exception and has a very wide confidence interval. Much more data would be required to narrow the interval here. On the other hand, the data available for the third period presents less certainty in the efficiency of treatment (Table 12). The confidence intervals in general are much wider and in fact for many constitutents it is not certain whether the concentration increased or decreased with treatment. Tetrachloroethylene, m-xylene, and the methylnaphthalenes are good examples of this. More data were generally available for each constituent during the third period, but the data had a

greater spread and less was above the detection limit. More data would be required to reduce these uncertainties. The greater spread is partially a result of the significant decrease in influent concentration at Water Factory 21 following the changeover from trickling-filter to activated-sludge treatment of the source water. The concentration of several constituents was then lowered to near the detection limit where variance due to analytical errors became highly significant.

A comparison between influent (unchlorinated) and effluent concentrations is given in Table 13 for the two periods to illustrate the changes in influent water which occurred. Also included in the table are the levels of significance for the differences between the two periods based upon a t-test comparison. Values of 0.05 or less indicate the differences are highly significant.

For COD and most trace organics there was a large and significant decrease in concentration between the two periods. The greatest decrease in general was among the aromatic hydrocarbons, which were reduced almost two orders of magnitude. The decrease in concentration was about 60 to 90 percent for the chlorobenzenes, phthalates, and PCBs, which was about the same as the COD reduction. On the other hand, the trihalomethanes increased in concentration. The concentration of certain compounds did not change significantly. These included the chlorinated ethanes and ethylenes, diisobutylphthalate, and lindane. In general, industrial waste segregation and activated-sludge treatment greatly improved the quality of influent water to WF-21.

The comparison between effluent concentrations during the second and third periods is interesting. For several trace organic substances no significant difference could be found between effluent concentrations between these two periods. This does not necessarily mean that there are no differences, it may only mean that there is insufficient data to show a significant difference. Many of the effluent organics have concentrations near or well below the detection limit, thus contributing to the uncertainty of the true concentration. A general conclusion from the data available is that WF-21 is capable of removal to near or below the detection limit of many important trace organics with a wide range in volatility and polarity.

The case of tetrachloroethylene is an exception to the above. Here, the effluent concentration increased significantly between the second and third periods. The increase occurred from the beginning of the third period between sampling points Q8 and Q9 after the final chlorination basin was coated with a tetrachloroethylene containing coal-tar epoxy in order to reduce concrete corrosion from low pH due to chlorination. Thus the water became contaminated with this compound during treatment.

HEAVY METALS

Figures 17 and 18 illustrate the distributions of heavy metals in the influent and effluent of Water Factory 21 during the third period. Tables 14 and 15 are summaries of geometric mean influent and effluent heavy metal concentrations and percentage overall removals both during the second and

TABLE 13. COMPARISON BETWEEN INFLUENT AND EFFLUENT CONCENTRATIONS OF ORGANIC SUBSTANCES FOR SECOND AND THIRD PERIODS

Constituent	Influent (Q1) Concentration (µg/l)		Percent Change	Sig. Level of Diff.	Effluent (Q9) Concentration (µg/l)		Percent Change	Sig. Level of Diff.
	Second Period	Third Period			Second Period	Third Period		
COD	141,000	47,000	-67	0.002	17,000	12,000	-29	0.002
Chloroform	1.6	3.2	100	0.002	7.3	8.6	18	0.5
Bromodichloromethane	0.09	0.53	490	0.002	2.1	2.7	29	0.5
Dibromochloromethane	0.15	0.69	360	0.01	0.78	1.3	67	0.1
Bromoform	0.12	0.40	230	0.1	0.17	0.38	123	0.05
1,1,1-Trichloroethane	4.7	3.2	-32	0.2	0.07	0.20	186	0.1
Trichloroethylene	0.9	0.74	-18	0.8	0.02	<0.1	?	?
Tetrachloroethylene	0.6	1.7	183	0.01	0.05	0.83	1560	0.002
Chlorobenzene	2.5	0.14	-94	0.002	0.05	0.05	0	0.8
1,2-dichlorobenzene	2.4	0.64	-73	0.002	0.03	0.02	33	0.8
1,3-Dichlorobenzene	0.68	0.16	-76	0.002	0.01	<0.02	?	?
1,4-Dichlorobenzene	2.1	1.9	-10	0.8	0.02	0.012	-40	?
1,2,4-Dichlorobenzene	0.46	0.11	-76	0.01	0.01	0.000	>90	?
Ethylbenzene	1.4	0.043	-97	0.002	0.03	0.014	-53	0.05
Naphthalene	0.57	0.033	-94	0.002	0.03	0.010	-67	0.1
1-Methylnaphthalene	0.86	0.008	-99	0.002	0.04	<0.02	<-50	?
2-Methylnaphthalene	1.00	0.010	-99	0.002	0.02	<0.02	?	?
Dimethylphthalate	16	4.8	-70	0.002	1.7	0.47	-72	0.05
Diisobutylphthalate	2.9	4.7	62	0.2	0.74	0.27	-63	0.5
Bis-[2-ethylhexyl] phthalate	28	11	-61	0.002	3.2	3.1	-3	0.8
Polychlorinated biphenyls measured as Aroclor 1242	3.3	0.47	-86	0.002	<0.3	<0.3	?	?
Lindane	0.19	0.14	-26	0.5	<0.05	<0.05	?	?

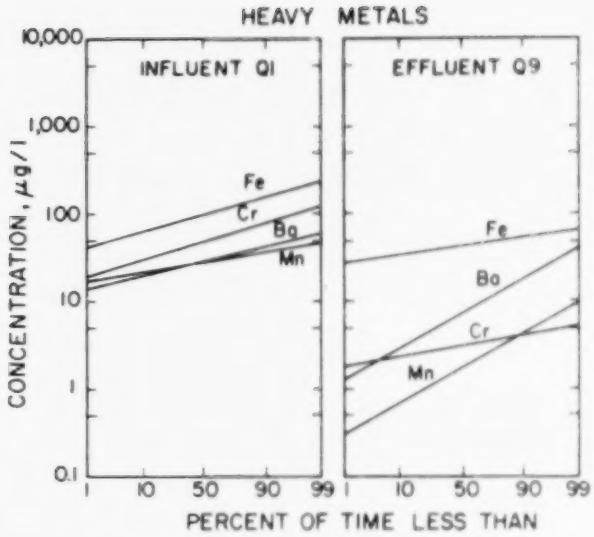


Figure 17. Distribution of heavy metal concentrations in the influent and effluent during third period.

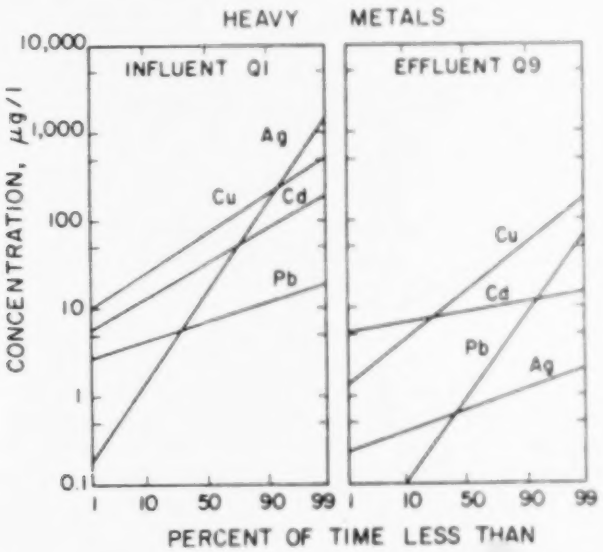


Figure 18. Distribution of heavy metal concentrations in the influent and effluent during third period.

TABLE 14. SUMMARY OF HEAVY METAL CONCENTRATIONS AND REMOVALS BY AWT DURING SECOND PERIOD

Heavy Metal	Geom. Mean Conc., µg/l		Percent Removal	
	Influ. Q1	Efflu. Q8	Average	95% Conf. Inter. for Avg.
Ag	3.0	2.5	17	-7 to 34
Ba	77	26	66	57 to 74
Cd	26	1.3	95	93 to 96
Cr	140	18	87	83 to 90
Cu	250	20	92	89 to 94
Fe	280	36	87	81 to 91
Hg	1.6	1.7	-6	-100 to 44
Mn	33	3.7	89	85 to 91
pb	16	2.2	86	76 to 92
Se	<2.5	<4	-	-
Zn	350	81	77	62 to 86
As	<5	<5	-	-

third periods. During period two more analyses were made and the more highly polluted trickling-filter effluent was being received at WF 21. For this period, the confidence intervals for percent removal are not as broad as during the third period, although results are comparable. The average influent concentrations of heavy metals were generally greater during the second period, although the differences between the two periods are not as great as was generally found for trace organic contaminants. Substantial removal of many heavy metals was obtained by treatment.

VIRUS

During the three years of virus monitoring by James M. Montgomery, Engineers, with the assistance of the California Department of Public Health, waters examined included plant influent, lime clarified effluent, RO

TABLE 15. SUMMARY OF HEAVY METAL CONCENTRATIONS AND REMOVALS BY AWT DURING THIRD PERIOD

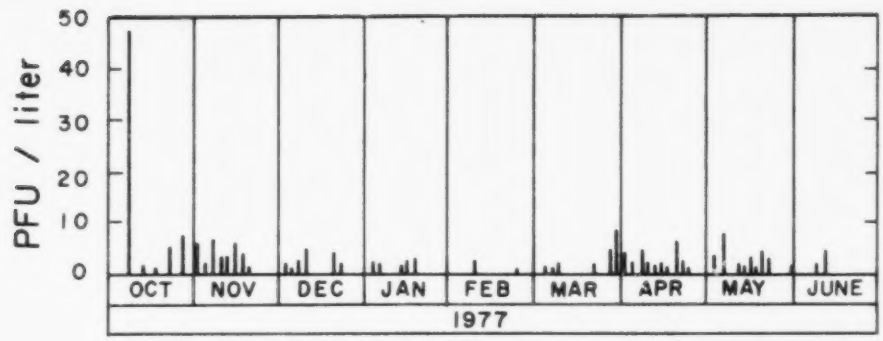
Heavy Metal	Geom. Mean Conc., µg/l Infl. Q1	Efflu. Q8	Percent Removal Average	95% Conf. Inter. for Avg.
Ag	1.2	0.7	42	-24 to 73
Ba	30	7.4	75	41 to 90
Cd	33	9.5	71	47 to 84
Cr	48	3.1	94	90 to 96
Cu	72	16	78	16 to 94
Fe	98	42	57	40 to 70
Hg	<1	<1	-	-
Mn	29	1.7	94	86 to 97
Pb	7.1	1.0	86	-164 to 99
Se	<5	<5	-	-
Zn	127	<100	>21	-
As	<5	<5	-	-

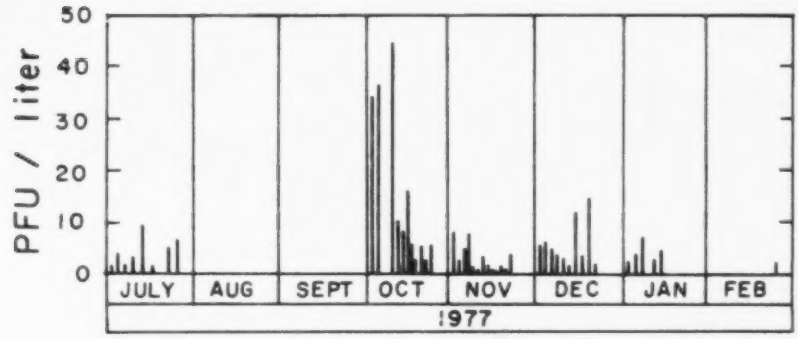
influent, RO effluent, chlorinated effluent, and blended injection water. In addition, granular activated carbon from three different carbon adsorption contactors was examined. Since the beginning of the project, 156 assays were done on the plant influent. The geometric mean concentration entering the plant was 1.1 PFU per liter during phase two with trickling filter influent and only 0.13 MPNCU per liter during the third phase with activated sludge influent. Also, different virus assay methods were used during these two periods. The BGM liquid culture technique used during the third period was found to be about three times more sensitive than the BGM plaque technique used during the second period. Thus the difference between the two periods was even greater than indicated by the above numbers.

Results show the log mean concentration entering the plant was 1.1 plaque-forming units per liter. A seasonal variation similar to that reported by other investigators has been observed. Figure 19 shows the variation in natural viruses in WF-21 influent and indicates that the peak occurs during late summer and early fall, with the highest concentrations during October. A partial summary of the types of viruses identified in the WF-21 influent is shown in Table 16, which indicates that the predominant virus type found was Polio 2. The next most common types were Echo 1 and Echo 17, followed by Reo and Echo 14. The CDPH used a greater number of cell lines than JMM-ERL, and this resulted in the greater variety of identifications by them shown.

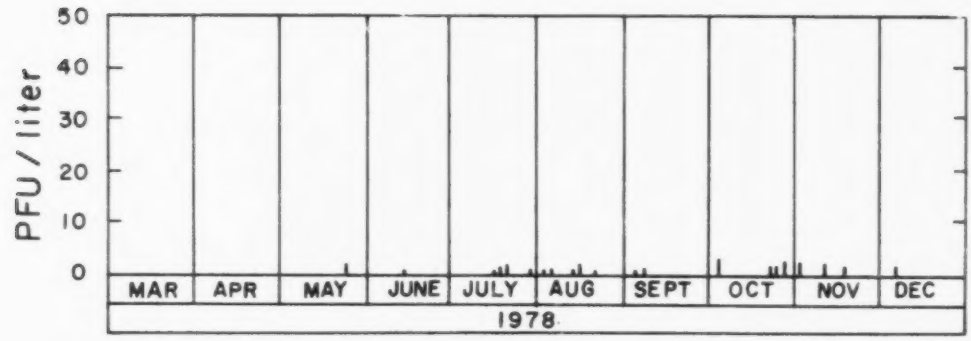
Evaluation of WF-21 plant processes has shown the treatment to be very effective in removing virus. The lime clarification process has been found to remove 98% to 99.9% of viruses present, based on BGM and PAG assay systems, respectively. Limited work was completed on the RO influent, which is unchlorinated activated carbon effluent, and on the RO effluent. No positive samples were ever found at these sample locations. In addition, 19 samples of the blended injection water were tested, and all proved negative.

There have been 123 samples tested on the chlorinated AWT effluent at Q9. Of these samples, two positives were found. The first incident occurred during the second period on March 1, 1977, and the isolate was identified as polio 2. The first positive isolated may have been caused by high turbidity (2.3 TU) resulting from carbon fines in the chlorinated effluent. Another possible explanation for the positive virus occurrence is sample contamination during concentration or sample assay. This possibility could not be ruled out. The second incident also occurred during period two on October 18, 1977, with the isolation of a virus identified as Echo 7. This second positive finding was also associated with high turbidity in the Q9 water (1.0 TU), the presence of 4/100 ml total coliforms, and a low total chlorine residual of 5.4 mg/l. A possible explanation for the occurrence of this virus may be a combination of the presence of carbon fines in the chlorinated effluent and a malfunction in the chlorine analyzers, which resulted in a lower than normal applied chlorine dose. It is believed that cross-contamination was less likely in this incident because of precautionary measures instituted on site at the virus analysis laboratory as a result of the March 1, 1977 isolate.





a. Second Period



b. Third Period

Figure 19. Seasonal variations in viruses in Water Factory 21 influent.

TABLE 16. TYPES OF VIRUSES IDENTIFIED
IN INFLUENT TO WATER FACTORY 21

CDPH#	JMM-ERL#
Polio 2 (27)*	Polio 2 (6)
Echo 1 (17)	Coxsackie B5 (5)
Echo 7 (16)	Echo 7 (1)
Reo 2 (12)	Echo 25 (1)
Echo 14 (8)	Polio (1)
Coxsackie B5 (8)	
Polio 3 (7)	
Echo 8 (6)	
Reo (6)	
Unknown (5)	
Echo 12 (5)	
Coxsackie B4 (5)	
Coxsackie B2 (4)	
Coxsackie B3 (3)	
Echo 11 (3)	
Reo 1 (3)	
Coxsackie B6 (2)	
Coxsackie A17 (2)	
Coxsackie A13 (1)	
Coxsackie A18 (1)	
Coxsackie A20 (1)	
Echo 3 (1)	
Echo 9 (1)	
Echo 19 (1)	
Polio 1 (1)	

*Numbers in parentheses indicate frequency of occurrence

#CDPH, California Department of Public Health; JMM-ERL, James M. Montgomery Environmental Research Laboratory, the Subcontractor for the virus monitoring program.

SECTION 8

EFFECTIVENESS OF INDIVIDUAL PROCESSES

GENERAL SUMMARY

Introduction

The general overall effectiveness of WF-21 inremoval of inorganic, organic, and biological contaminants was given in Section 7. This removal was the result of contribution by each of the processes. While some processes are generally thought to be useful for one specific purpose, it is generally found that they can efficiently remove other contaminants. For example, air stripping was originally included at WF-21 for removing ammonia, but since has been found to be important in the removal of several chlorinated and volatile organics. Also, reverse osmosis was originally included to meet mineral requirements, but is one of the most efficient processes for removing high molecular weight organic materials.

This section begins with an overview of the contribution each process makes in the removal of inorganic and organic materials. This is followed by a more detailed discussion of each process.

Organics Removal

The removal of COD by various processes was described in some detail in Section 7. Lime clarification, air stripping, activated carbon adsorption, and reverse osmosis all play important parts. Chlorination also plays a significant role; it results in the formation of chlorinated organics. The effect on trihalomethane formation was presented in Section 7.

In order to illustrate that different processes have different removal characteristics for different trace organic chemicals the distributions of selected chemicals are presented in Figures 20 through 23. Figure 20 indicates that 1,4-dichlorobenzene was removed well by the stripping process (between Q2 and Q4), and by activated carbon (between Q6 and Q9). Figure 21 indicates that significant removals of tetrachlorethylene occurred only during stripping. These results are particularly interesting because the blowers were not operating in the stripping towers during this period; removal took place as the water cascaded down through the tower with no forced air circulation.

Figure 22 indicates that one of the aromatic hydrocarbons, ethylbenzene, appears to have been partially removed by several processes, although concentrations were so low that confidence intervals are quite broad for these results. Finally Figure 23 indicates the diisobutylphthalate was removed

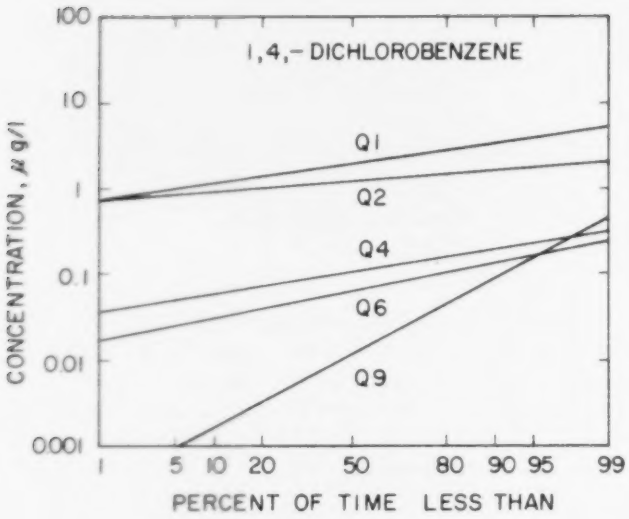


Figure 20. Distribution of 1,4-dichlorobenzene concentrations at various sampling points during third period.

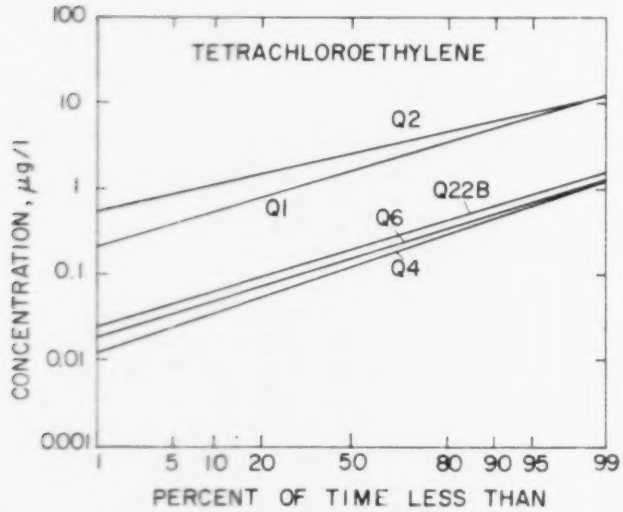


Figure 21. Distribution of tetrachloroethylene at various sampling points during third period.

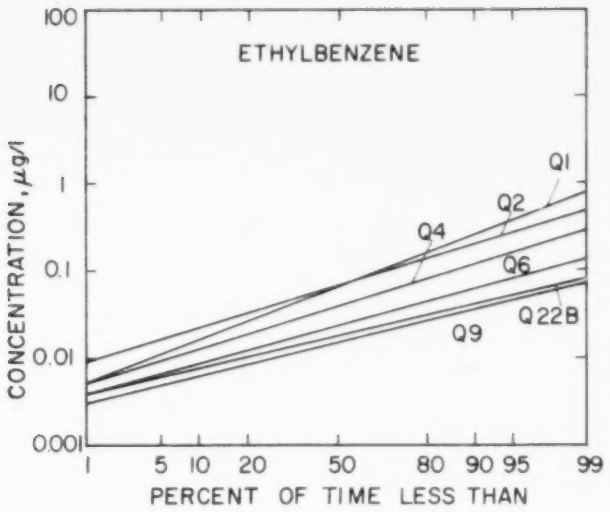


Figure 22. Distribution of ethylbenzene at various sampling points during third period.

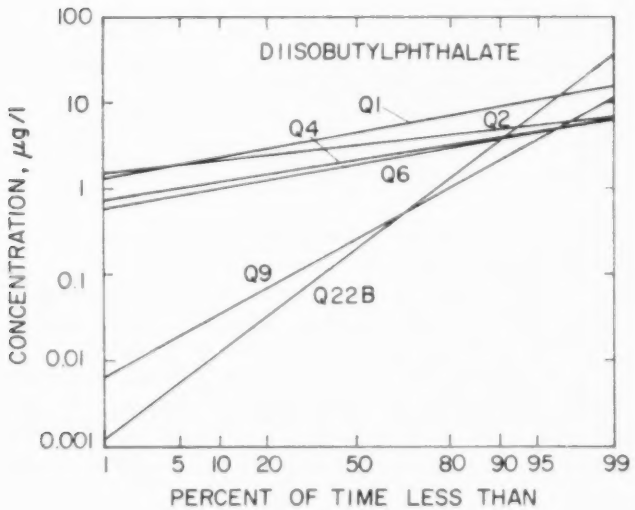


Figure 23. Distribution of diisobutylphthalate at various sampling points during third period.

primarily by activated-carbon adsorption. Also passage through reverse osmosis appeared to increase the spread factor for this material significantly. This phenomenon needs further exploration. It may simply have been an analytical artifact because concentrations were generally below the detection limit. Phthalates are particularly difficult to quantity because of poor detector sensitivity and difficulty in preventing sample contamination.

Heavy Metals Removal

Figures 24 and 25 indicate the lognormal distributions for cadmium and chromium at various sampling locations at WF-21. Both metals were removed most effectively by lime treatment (Q2), as was found true for most heavy metals. The dashed lines indicate the maximum contaminant level for these metals as set for drinking water by the EPA Interim Primary Drinking Water Regulations. Lime treatment was sufficient to reduce cadmium concentration below its MCL 99 percent of the time, but reduced chromium below its MCL only about 75 percent of the time. Subsequent treatment through GAC (Q8) reduced chromium sufficiently so that the MCL was exceeded only about 8 percent of the time. Thus although the effect of additional treatment seems small, the added benefit in terms of meeting a given MCL may be significant.

LIME TREATMENT

The effectiveness of lime treatment during both the second and third periods in reducing the concentration of heavy metals, coliforms, COD, and other miscellaneous contaminants is given in Table 17. Indicated are the influent concentrations, the percent removal based upon the difference between geometric means, and the 95 percent confidence interval for the percent removal. In general heavy metals are removed quite effectively by lime treatment. An exception is mercury. Also removed to a significant extent are flouride, organic nitrogen, turbidity, and COD. Boron and ammonia nitrogen were little affected by lime treatment. Coliforms which were high in concentration in the influent were reduced by greater than 99.999% by lime treatment.

Calculated reductions in trace organic materials by lime treatment are listed in Table 18 for the second and third periods. The compounds are listed in order from highest to lowest removal during the third period. Some removal of pesticides, phthalates, PCBs, and perhaps chlorinated benzenes appears to have occured during lime treatment. These materials perhaps absorded to some extent on the suspended materials in the plant influent, or perhaps to the lime precipitate. Removals appear to be somewhat higher in general during the second period, perhaps because the concentration of suspended material and the trace organic compounds, were considerably higher in the plant influent.

Many trace organics were not removed by lime treatment during the third period, and in fact appear to have increased in concentration (negative percent removal). This includes the aromatic hydrocarbons and the halogenated methanes, ethanes, and ethylenes. No confirmed explanation is available for these increases. Perhaps some contamination with oil or

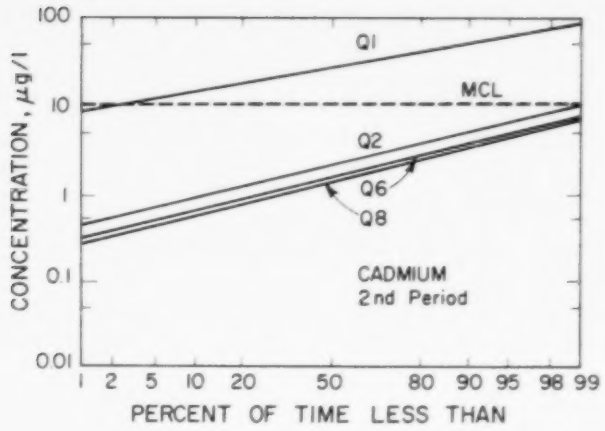


Figure 24. Frequency distribution for cadmium at various sampling locations during the second period.

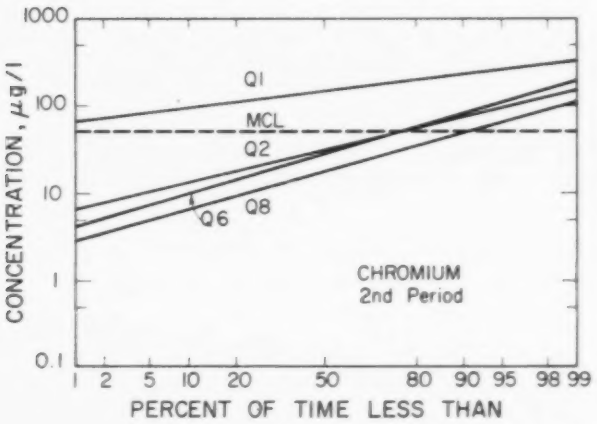


Figure 25. Frequency distribution for chromium at various sampling locations during the second period.

TABLE 17. REMOVALS OF HEAVY METALS AND MISCELLANEOUS CONTAMINANTS BY LIME TREATMENT

Contaminant	Second Period Inf. Conc. Q1	Second Period Eff. Conc. Q2	Second Period % Removal (95% CI)	Third Period Inf. Conc. Q1	Third Period Eff. Conc. Q2	Third Period % Removal (95% CI)
Ag, µg/l	3.0	2.5	17 (-8 to 37)	1.2	0.46	61 (-54 to 90)
Ba, µg/l	77	32	58 (48 to 67)	30	9.2	69 (52 to 80)
Cd, µg/l	26	2.0	92 (90 to 94)	33	8.7	74 (47 to 87)
Cr, µg/l	140	30	79 (72 to 84)	48	6.6	86 (78 to 92)
Cu, µg/l	250	68	73 (67 to 78)	72	23	68 (20 to 87)
Fe, µg/l	280	22	92 (88 to 95)	98	13	87 (76 to 93)
Hg, µg/l	1.6	1.9	-18 (-110 to 34)	<1	<1	-
Mn, µg/l	33	1.5	95 (93 to 97)	29	2.6	91 (65 to 98)
Pb, µg/l	16	2.9	82 (74 to 88)	7	3.1	56 (15 to 78)
Se, µg/l	<2.5	<2.5	- -			
Zn, µg/l	350	135	61 (36 to 77)	127	<100	>21
As, µg/l	<5	<5	- -	<5	<5	-
B, mg/l	0.94	0.81	14 (5 to 22)			
Org-N, mg/l	7.4	3.1	85 (84 to 86)	2.0	1.0	50 (46 to 54)
NH_3-N, mg/l	30	26	13 (6 to 20)	4.0	5.9	-48 (-79 to -21)
Turbidity, TU	42	1.2	97 (96.9 to 97.3)	6.5	0.54	92 (90 to 93)
COD, mg/l	141	52	63 (62 to 64)	47	27	42 (40 to 45)
Coliforms, MPN/100 ml						
Total	89×10^6	0.21	>99.999(>99.999)	1.6×10^6	0.2	>99.999(>99.999)
Fecal	25×10^6	<1	>99.999(>99.999)	0.6×10^6	0.08	>99.999(>99.999)

TABLE 18. REMOVALS OF TRACE ORGANICS BY LIME TREATMENT DURING THE SECOND AND THIRD PERIODS

	Second Period			Third Period		
Contaminant	Inf. Conc. Q1 µg/l	Eff. Conc. Q2 µg/l	% Removal (95% CI)	Inf. Conc. Q1 µg/l	Eff. Conc. Q2 µg/l	% Removal (95% CI)
Di-n-butyl-phthalate				0.79	0.23	71 (-80 to 95)
1,2,4-Trichloro-benzene	0.46	0.22	52 (-96 to 88)	0.11	0.035	68 (2 to 90)
Bis-[2-diethylhex-yl]-phthalate				11	3.8	65 (32 to 82)
Lindane				0.14	<0.05	>64
1,3-Dichloro-benzene	0.68	0.12	82 (15 to 96)	0.16	0.10	38 (10 to 57)
Dimethylphthalate				4.8	3.1	35 (-5 to 60)
Diisobutyl-phthalate				4.7	3.2	32 (12 to 48)
1,4-Dichloroben-zene	2.1	1.02	51 (-7 to 78)	1.85	1.29	30 (16 to 42)
PCBs as Aroclor 1242				0.47	0.37	21 (-15 to 46)
1,2-Dichloroben-zene	2.4	1.2	50 (-71 to 85)	0.64	0.56	12 (-54 to 50)
2-Methylnaphtha-lene				0.01	0.009	10 (-253 to 77)
Bromodichloro-methane	0.09	0.21	-133(-1340 to 62)	0.53	0.56	-6 (-33 to 16)
Chlorobenzene	2.5	3.0	-20 (-174 to 47)	0.14	0.15	-7 (-80 to 36)
Dibromochloro-methane				0.69	0.79	-14 (-42 to 8)
Trichloroethy-lene	0.9	0.21	77 (-19 to 95)	0.74	0.86	-16 (-270 to 63)
Heptaldehyde				0.10	0.12	-20 (-132 to 38)
Naphthalene	0.57	0.21	63 (-22 to 89)	0.033	0.041	-24 (-548 to 76)
Chloroform	1.6	1.09	32 (-26 to 63)	3.2	4.1	-30 (-79 to 5)
1,1,1-Trichloro-ethane	4.7	0.94	80 (-30 to 97)	3.3	4.7	-45 (-198 to 30)
Tetrachloro-ethylene	0.6	0.16	73 (10 to 92)	1.67	2.5	-50 (-141 to 7)
p-Xylene				0.015	0.023	-53 (-206 to 23)
Ethylbenzene	1.4	0.23	83 (62 to 93)	0.043	0.067	-56 (-202 to 20)
Styrene				0.048	0.076	-58 (-294 to 36)
Tribromomethane				0.40	0.67	-68 (-143 to -15)
1-Methylnaphtha-lene				0.008	0.019	-138 (-510 to 8)
m-Xylene				0.035	0.086	-146 (-329 to 41)

other petroleum product occurred during this stage of treatment. Caution must be exercised in overinterpreting these data, however, because of the wide confidence intervals on the percentage removals.

AIR STRIPPING

The air stripping towers were designed for removal of ammonia through forced air circulation which exposed the wastewater to about 3000 m^3 of air per m^3 of water. Forced air circulation was provided during the second period when the influent ammonia nitrogen concentration was high, but not during the third period when the ammonia level dropped considerably. The towers were used then primarily for the removal of volatile trace ogranics for which they were found to be very effective.

The removal of ammonia by the stripping towers during the second and third period are listed in Table 19. With forced air circulation during the second period the removal was about 81 percent, but when this was stopped during the third period, removal dropped to 25 percent. The 25 percent removal is still significant since it means that less chlorine is required in subsequent removal of ammonia by oxidation.

Table 20 indicates the removal of various trace organic materials which were obtained by air stripping. The compounds are listed in order from the highest to the lowest percentage removal during the third period. A comparison with removals obtained during the second period suggests approximately the same order. It is evident that removal of these materials did not depend upon forced air circulation as the percentage removals were similar for the two periods. This indicates that stripping of volatile organics is kinetically limited primarily by transfer through the liquid rather than the air film. Thus, power requirements for stripping of organics can be small.

Table 20 indicates that the chlorinated benzenes and the halogenated methanes, ethanes, and ethylenes are effectively removed by air stipping, but the phathalates, aromatic hydrocarbons, and cyanides are not.

During this evaluation it was also found that several of the volatile compounds appeared to be removed by the full scale reverse osmosis units, which is contradictory to the observations made earlier with a similar pilot scale reverse osmosis unit. It was determined that these removals took place in the small decarbonators, described in Appendix B, which follow the reverse osmosis system. Table 21 is a summary of trace organic removal through the decarbonator. The influent concentration is the effluent from the reverse osmosis unit (Q22R). Again, the halogenated methanes, ethanes, and ethylenes were removed efficiently by air stripping. The decarbonator is a reasonably inexpensive process (about $20,000 capital cost to treat 0.22 m^3/s), and thus such a unit has excellent potential for removal of some trace organics.

TABLE 19. AMMONIA REMOVAL BY AIR STRIPPING

	Second Period	Third Period*
Influent (Q2) NH_3-N		
Average (M), mg/l	26	5.9
Range, mg/l	4-85	0.6-47
Spread Factor, S	1.54	2.03
No. of Samples	226	164
Effluent (Q4) NH_3-N		
Average (M), mg/l	5	4.4
Range, mg/l	1-18	1.1-12
Spread Factor, S	1.80	1.68
No. of Samples	206	90
Percent Removal		
Average	81	25
95% CI	79-83	13-36

*No forced air circulation

TABLE 20. REMOVAL OF TRACE ORGANICS BY AIR STRIPPING

Contaminant	Period Two Inf. Conc. Q2 µg/l	Period Two Eff. Conc. Q4 µg/l	Period Two Removal % Avg.	Period Two Removal % 95% CI	Period Three Inf. Conc. Q2 µg/l	Period Three Eff. Conc. Q4 µg/l	Period Three Removal, % Avg.	Period Three Removal, % 95% CI
Tetrachloroethylene					2.5	0.13	95	88 to 98
1,4-Dichlorobenzene	1.0	0.03	97	88 to 99	1.3	0.10	92	89 to 94
1,1,1-Trichloroethane	0.94	0.09	90	0 to 99	4.7	0.43	91	76 to 96
1,2-Dichlorobenzene	1.2	0.18	85	-10 to 98	0.56	0.07	88	61 to 96
Tribromomethane					0.67	<0.1	>85	-
Heptaldehyde					0.12	<0.02	>83	-
1,3-Dichlorobenzene	0.12	0.02	83	-46 to 98	0.10	0.02	83	60 to 93
Bromodichloromethane	0.21	0.08	62	-320 to 97	0.56	<0.1	>82	-
Dibromochloromethane					0.79	0.14	82	76 to 87
Chloroform	1.1	0.18	83	70 to 91	4.1	0.88	79	64 to 87
Trichloroethylene	0.21	0.013	94	-73 to 100	0.86	<0.2	>77	-
Styrene					0.076	0.037	51	-180 to 92
1-Methylnaphthalene					0.019	0.011	42	-170 to 88
1,2,4-Trichlorobenzene	0.22	0.11	50	-440 to 95	0.035	0.02	40	-290 to 91
Ethylbenzene	0.23	0.10	57	-110 to 91	0.067	0.041	39	-58 to 76
Diisobutylphthalate					3.2	2.3	28	-1 to 49
Chlorobenzene/o-Xylene	3.0	0.11	96	89 to 99	0.15	0.11	27	-46 to 63
m-Xylene					0.086	0.07	19	-84 to 64
Naphthalene	0.21	0.18	14	-257 to 79	0.041	0.37	10	-840 to 91
Dimethylphthalate					3.1	2.8	10	-79 to 54
PCB as Aroclor 1242					0.37	0.36	3	
2-Methylnaphthalene					0.009	0.009	0	-740 to 88
Heptylcyanide					0.047	0.048	-2	-160 to 60
p-Xylene					0.023	0.031	-35	-200 to 39

TABLE 21. AIR STRIPPING OF TRACE ORGANICS BY DECARBONATOR FOLLOWING REVERSE OSMOSIS

Contaminant	Inf. Conc. g/l	Eff. Conc. g/l Q22B	Removal, % Avg.	Removal, % 95% CI
Bromodichloromethane	4.2	0.67	84	75 to 90
Chloroform	10.6	1.83	83	76 to 88
Dibromochloromethane	1.93	0.54	72	54 to 83
Tribromomethane	0.59	0.18	69	31 to 86
1,1,1-Trichloroethane	0.21	0.09	57	-98 to 91
Tetrachloroethylene	0.07	0.04	43	-131 to 86

RECARBONATION AND FILTRATION

These unit processes were found not to be highly effective in trace organic or heavy metal removal. The changes in concentration across these two unit processes can be obtained by comparing the concentrations at the Q4 and Q6 sampling points as listed in Appendices C and E.

However, because of chlorination in the recarbonation basin for algae control and disinfection, the concentration of trihalomethanes increased significantly between points Q2 and Q6 (see Appendices C and E for details). For example, during the second period the geometric mean chloroform concentration increased from 0.2 to 8.4 g/l, and during the third period from 0.9 to 5.3 g/l. Use of alternative disinfectants such as ClO_2, or covering of the recarbonation basin could perhaps reduce this problem.

ACTIVATED CARBON ADSORPTION

General Performance

Tables 22 and 23 present summaries of the general performance of granular activated carbon (GAC) for the removal of COD, TOC, trace organic contaminants and various heavy metals during periods two and three. During period two, about 14 percent of the GAC in each column was regenerated every 40 to 70 days, while during the third period, about 50 percent was regenerated about once every six months.

The trace organic contaminant data in Table 22 are arranged in order of removal efficiency by GAC during the third period. In general, chlorinated benzenes, some of the phthalates and aromatic hydrocarbons, and the brominated

TABLE 22. REMOVAL OF ORGANIC MATERIALS BY GAC DURING PERIODS TWO AND THREE

Contaminant	Period Two			Period Three		
	Inf. Conc. (Q6)	*Eff. Conc. (Q8 or Q9)	% Removal (95% CI)	Inf. Conc. (Q6)	*Eff. Conc. (Q9 or Q22A)#	% Removal (95% CI)
COD	42	16.6	60 (58 to 63)	24	12.3	49 (46 to 52)
TOC	14	7.0	51 (48 to 54)			
1,4-Dichlorobenzene	0.02	0.02	17 (-750 to 90)	0.07	0.001	98 (43 to 100)
1,2-Dichlorobenzene	0.17	0.03	82 (0 to 97)	0.02	0.002	91 (-150 to 100)
Diisobutylphthalate				2.0	0.27	87 (61 to 95)
Tribromomethane				0.41	0.08	81 (40 to 94)
Dimethylphthalate				1.3	0.47	64 (24 to 83)
Chlorobenzene/o-xylene	0.09	0.05	46 (-5 to 72)	0.11	0.04	63 (30 to 80)
Bromodichloromethane	4.8	1.3	72 (46 to 86)	1.8	0.81	54 (5 to 77)
Dibromochloromethane	1.4	0.23	84 (58 to 94)	0.65	0.31	52 (2 to 77)
m-xylene				0.05	0.023	50 (7 to 73)
Naphthalene				0.05	0.023	50 (-8 to 76)
Di-n-butylphthalate				0.59	0.33	44 (-90 to 84)
Carbon Tetrachloride				0.07	0.06	20 (-110 to 70)
Ethylbenzene	0.06	0.03	45 (3 to 69)	0.02	0.019	17 (-77 to 61)
Bis-[2-ethylhexyl]-phthalate				3.4	3.1	9 (-69 to 51)
1-Methylnaphthalene				0.02	0.009	0 (-660 to 87)
Tetrachloroethylene	0.04	0.01	72 (-260 to 98)	0.16	3.1	-6 (-190 to 61)
Methylene chloride	1.5	1.6	-7 (-98 to 43)			
1,1,1-Trichloroethane				0.16	0.018	-12 (-430 to 76)
2-Methylnaphthalene				0.07	0.02	-18 (-150 to 45)
Chloroform	8.2	6.7	21 (-70 to 63)	5.3	7.5	-41 (-146 to 19)

*Geometric mean conc. in µg/l except TOC and COD which are in mg/l.
#Q22A (unchlorinated activated carbon effluent) for VOA and CLSA constituents, Q9 for SEA constituents.

trihalomethanes were removed at least as efficiently as COD. The one and two carbon chlorinated compounds, on the other hand, were not removed by GAC under the conditions of operation at WF-21. Fortunately, these compounds are removed effectively by stripping. Confidence intervals on percent removal are in general quite broad and so it is necessary to be careful in data interpretation.

The heavy metal data in Table 23 indicate that chromium, copper, and lead are partially removed by GAC treatment. Iron was fairly efficiently removed during the second period, but during the third period, GAC treatment increased the effluent iron concentration. This change is probably due to wear on the linings and increased corrosion of the GAC vessels. Since the efficiency of GAC for heavy metal removal was not of high priority during the third period, the number of samples collected for this purpose was low and the resulting confidence interval is broad. Thus, some caution is needed in drawing firm conclusions from the data.

TOC has frequently been proposed as a general monitoring tool for GAC performance rather than COD. At WF-21, however, COD is used more generally as a control parameter since the TOC instrument was not always operable, and TOC analysis has been of questionable accuracy. Table 24 is given for reference so that COD results may be translated in terms of TOC. The COD/TOC ratio generally lies between 2.0 and 3.0.

TABLE 23. REMOVAL OF HEAVY METALS BY GAC DURING PERIODS TWO AND THREE

	Period Two			Period Three		
Contaminant	Inf. Conc.* (Q6)	Eff. Conc. (Q8)	% Removal (95% CI)	Inf. Conc.* (Q6)	Eff. Conc. (Q8)	% Removal (95% CI)
Ag	2.6	2.5	4 (-27 to 27)	0.77	0.69	10 (-250 to 77)
Ba	26	26	0 (-37 to 27)	7.8	7.4	5 (-150 to 64)
Cd	1.4	1.3	7 (-32 to 35)	7.2	9.5	-32 (-210 to 43)
Cr	29	18	38 (9 to 58)	5.6	3.1	45 (-3 to 70)
Cu	56	20	64 (51 to 74)	36	16	56 (-85 to 89)
Fe	105	36	66 (41 to 80)	28	42	-50 (-530 to 64)
Hg	1.9	1.7	11 (-47 to 46)			
Mn	3.2	3.7	-16 (-83 to 27)	1.3	1.7	-35 (-270 to 51)
Pb	3.0	2.2	27 (-56 to 66)	3.1	1.0	68 (-780 to 99)

*Geometric mean conc. in µg/l

TABLE 24. COD TO TOC RATIOS AT VARIOUS SAMPLING LOCATIONS FOR DIFFERENT PERIODS OF OPERATION AT WF-21

Period	Parameter	Chem. Eff. Q2	Filt. Eff. Q6	GAC Eff. Q8
Two	COD*, mg/l	52 (N=274)	42 (N=272)	16.6 (N=264)
	TOC*, mg/l	21.5 (N=19)	14.4 (N=156)	7.0 (N=163)
	COD/TOC ratio	2.41	2.92	2.37
	95% CI for ratio	2.3-2.6	2.8-3.0	2.2-2.5
Three	COD*, mg/l	27 (N=156)		12.3 (N=125)
	TOC*, mg/l	10 (N=44)		6.2 (N=91)
	COD/TOC ratio	2.70		1.98
	95% CI for ratio	2.6-2.8		1.8-2.2

* Geometric Mean Concentration

Fresh Versus Old GAC

Figure 26 is a summary of the effectiveness of a single GAC column in the removal of COD towards the end of period 2 and through period 3. During period 2 with upflow operation, the column influent concentration of COD was generally greater than 35 mg/l and an average of about 30 mg/l of COD was removed. Whenever effluent COD from a column reached 20 mg/l, about 5.5 metric tons were regenerated, about 0.8 kg of COD was removed per kg of regenerated carbon.

With the beginning of period three, the influent COD decreased considerably so that carbon regeneration to maintain a planned 20 mg/l in the effluent did not need to be so frequent. One million gallons of throughput is equivalent to about one day of operation. Thus, almost 6 months of operation appears possible before regeneration. During this time COD removal by activated carbon treatment averaged about 7 mg/l, for a cumulative total over the period of about 1.7 kg COD per kg of regenerated carbon.

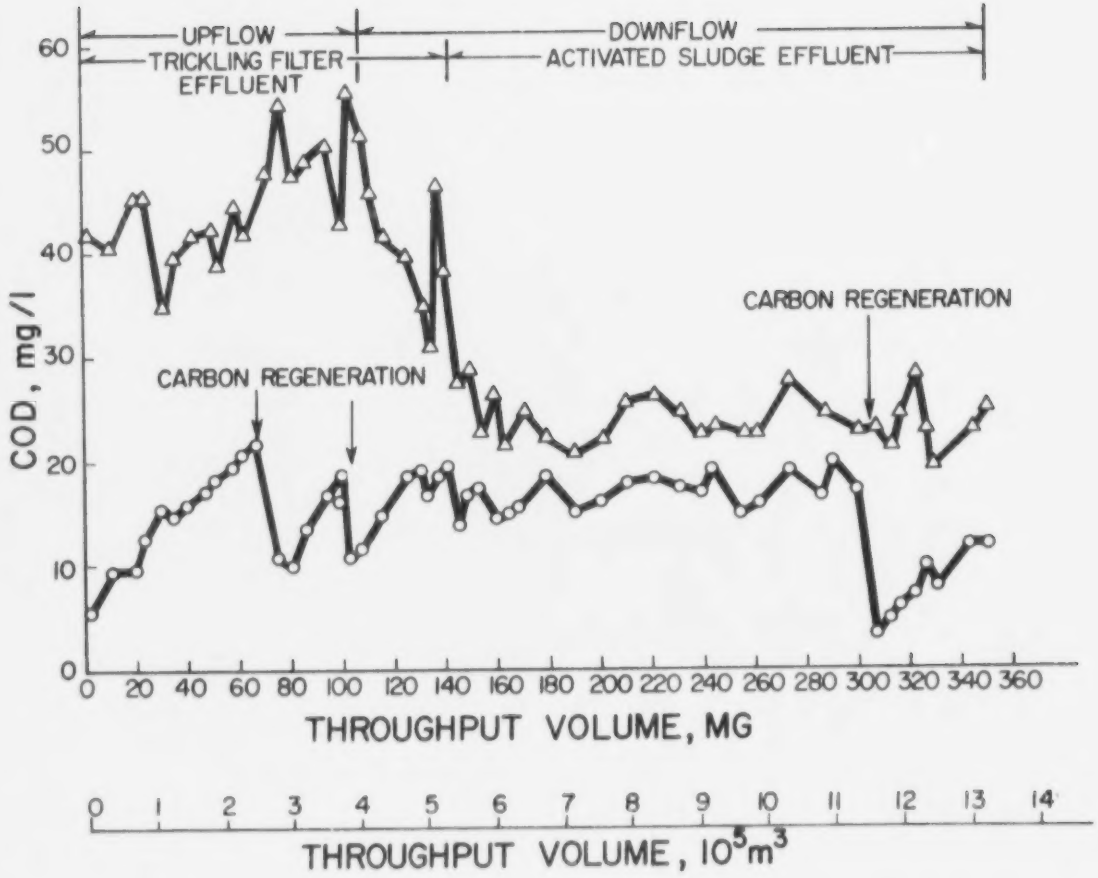


Figure 26. Influent and effluent COD for a typical GAC column during the latter part of Period 2 and into Period 3.

In order to evaluate the effect of biological processes within the activated carbon system, one GAC column, initially started during phase 2, was operated continuously with no regeneration. The COD removal by this system is illustrated in Figure 27. For the first 125 million gallons of throughput, COD removal gradually decreased. For the next 125 million gallons, COD removal remained nearly constant at about 32 percent. This is believed to be the result of biological removal or transformation of organics by microorganisms growing on the GAC. The trickling filter effluent received by WF-21 at that time was inefficiently treated and no doubt contained a significant proportion of biodegradable organics.

With the change to the more efficiently treated activated sludge wastewater, the fractional removal of COD by this GAC column decreased to about 20 percent after a short acclimation period. The operation of this column indicates that biological processes are significant in GAC performance, and may in part explain the high organic removals per kg of GAC obtained.

Trace Organics Removal by Fresh and Old GAC

A comparative evaluation was made of trace organics removal during the third period by a normally regenerated (fresh) GAC column and the old GAC column represented in Figure 28. The effluent from the fresh GAC is designated as Q7-12, and that from the old as Q7-5. At the beginning of this evaluation on July 5, 1978, about 7.5×10^4 m^3 had been passed through the "fresh" GAC since the previous regeneration, and a total of about 3.8×10^5 m^3 (100 million gallons) had been passed through this GAC since it was put in service. The "fresh" GAC had just been transferred to a new vessel and about 10 percent new GAC was added. Thus, the initial performance was similar to that of freshly regenerated GAC. Water was passed through the column at the design flow rate until September 1 when 100 percent of the GAC was regenerated. The unit was placed back into operation on October 1. Data on trace organics was gathered over the period from July 5 through December 31.

Figure 28 shows the COD of daily composite samples for the fresh and old GAC after the October 1 complete regeneration. The effluent COD from the fresh column was initially about 5 mg/l, which is typical for regenerated carbon, and rose fairly rapidly at a rate of about 0.17 mg/l/day for the first 60 days. This corresponds to an increase in effluent TOC of about 0.08 mg/l/day.

Normal practice at present is to regenerate only about one-half of the GAC in a bed. The rate of effluent COD increase is then about twice that depicted in Figure 28. This figure also indicates there is an apparent variation in effluent COD which parallels the variation in influent COD. This is important to consider when developing criteria for GAC performance and regeneration.

Table 25 is a comparative summary of the removal of trace organic materials by fresh and old GAC. The constituents are arranged in order from that with the highest calculated removal (by fresh GAC) to that with the lowest. Many of the constituents were present in low concentration, very

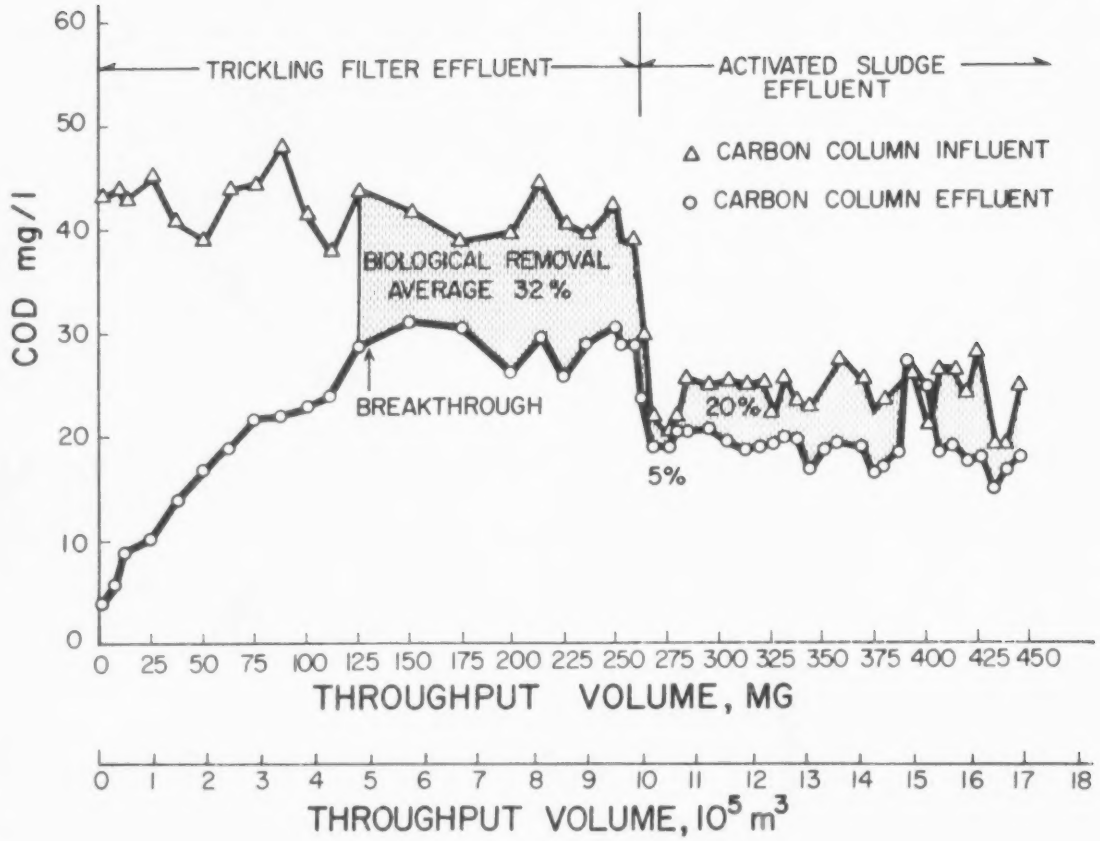

TRICKLING FILTER EFFLUENT
ACTIVATED SLUDGE EFFLUENT
△ CARBON COLUMN INFLUENT
○ CARBON COLUMN EFFLUENT
BIOLOGICAL REMOVAL AVERAGE 32 %
BREAKTHROUGH
20%
5%
COD mg/l
0 10 20 30 40 50 60
0 25 50 75 100 125 150 175 200 225 250 275 300 325 350 375 400 425 450
THROUGHPUT VOLUME, MG
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18
THROUGHPUT VOLUME, 10^5 m^3

Figure 27. Influent and effluent COD for a GAC column over an extended period without regeneration.

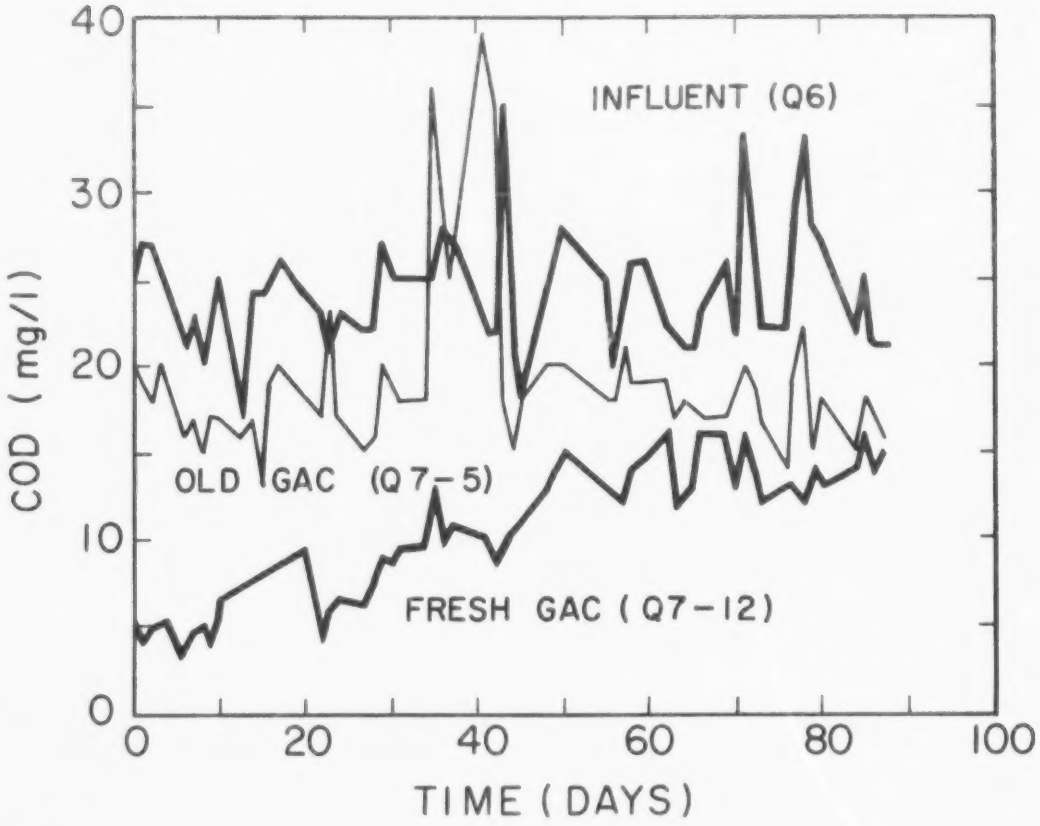


Figure 28. Comparison of influent and effluent COD concentrations with time for fresh and old GAC.

TABLE 25. AVERAGE PERCENTAGE REMOVAL OF TRACE CONTAMINANTS BY GAC AND 95% CONFIDENCE INTERVAL FOR AVERAGE PERCENTAGE REMOVAL

Contaminant	Fresh GAC (Q7-12) Removal %	Fresh GAC (Q7-12) 95% CI	Old GAC (Q7-5) Removal %	Old GAC (Q7-5) 95% CI	Level of Significance for Difference Between Effluent Means*
Heptaldehyde	97	59 to 100	88	32 to 98	0.5
Naphthalene	96	-13 to 100	91	33 to 99	>0.5
Pentachloroanisole	95	82 to 99	>87	-	-
Tribromomethane	95	-280 to 100	59	-65 to 90	0.5
1, 4-Dichlorobenzene	91	54 to 98	>70	-	-
Dibromochloromethane	86	22 to 98	5	-97 to 54	0.05
Diisobutylphthalate	83	30 to 96	87	72 to 94	>0.5
Styrene	80	-85 to 98	53	-30 to 50	>0.5
Bromodichloromethane	69	13 to 89	-7	-130 to 50	0.02
Diethylphthalate	66	-96 to 66	56	-33 to 86	>0.5
Dimethylphthalate	64	24 to 83	-30	-130 to 26	0.01
1,1,1-Trichloroethane	63	-110 to 93	69	-87 to 95	>0.5
Chlorobenzene/o-xylene	61	3 to 84	36	-3 to 61	0.5
m-Xylene	20	-130 to 71	61	20 to 81	0.5
p-Xylene	17	-400 to 87	-	-	-
Di-n-butylphthalate	15	-300 to 82	17	-200 to 77	>0.5
Bis-[2-ethylhexyl]-phthalate	3	-150 to 63	-41	-150 to 21	0.5
Chloroform	0	-130 to 55	-33	-170 to 34	0.5
Ethylbenzene	-4	-190 to 63	35	-51 to 72	0.5
Tetrachloroethylene	-44	-560 to 68	-19	-270 to 62	>0.5

* Values below 0.1 indicate differences are statistically significant

near the detection limit. Nevertheless, the data are adequate to indicate that many trace constituents are removed with high efficiency by GAC. However, this is not the case with all constituents, especially chloroform and several of the two-carbon chlorinated solvents.

A surprising result of this analysis is that the efficiency of removal of trace constituents by old GAC is generally comparable to that found with freshly regenerated material. In order to evaluate this further, a t-test was conducted to determine whether there was a statistically significant difference between the GAC effluent concentrations for any of the constituents. The data from this analysis are contained in the last column of Table 25. Small numbers, generally less than 0.1, indicate that the differences are statistically significant. Only with the two THMs, dibromochloromethane, bromodichloromethane, and with dimethylphthalate were the data adequate to show significant differences in performance between fresh and old GAC.

Effectiveness of GAC for Trihalomethane (THM) Removal

The difficulty of removing THMs and other halogenated one- and two-carbon compounds with GAC is well recognized and is indicated by the data in Tables 22 and 25. In general, THMs are removed much better by fresh GAC than with old GAC. Also, the more highly brominated THMs are removed more efficiently than chloroform. Further comparisons between the fresh and old GAC are shown in Figures 29 through 32. The water applied to GAC had been chlorinated in the recarbonation basin for control of algae. The higher effluent compared with influent concentrations of chloroform frequently found (Figure 29) perhaps were the result of additional formation during passage of the chlorinated water through the GAC column.

After about 100 days, the concentration of THMs in the influent to the GAC increased as a result of a short-term decrease in the influent ammonia concentration, and a resulting free chlorine residual in the recarbonation basin. GAC effluent concentrations appeared to be tempered with respect to influent concentrations. However, when the influent concentrations of THMs decreased after about 180 days, some desorption from the GAC took place and the effluent concentrations remained high for a short period during which they exceeded the influent concentrations. These results are similar for the fresh and old GAC, although the fresh GAC was in general more efficient in THM removal.

A comparison of the relative effectiveness of new versus old GAC for THM removal is given in Figure 32. With chloroform, fresh GAC after regeneration is just a little better than old GAC. With time, the difference diminished, and in the period after 180 days, the chloroform in the effluent from fresh GAC effluent was higher than from old GAC. Relative removal of brominated trihalomethanes by freshly regenerated GAC was much better. However, the ability of fresh GAC to remove these materials decreased rapidly so that within 50 days after regeneration, there was little difference in removal between fresh and old GAC.

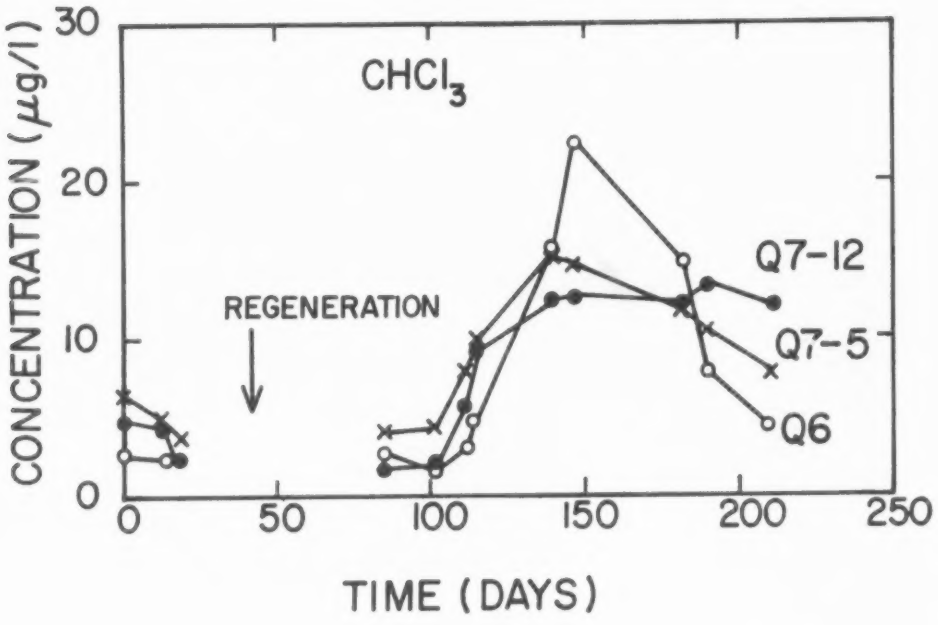


Figure 29. Comparison of chloroform removal by fresh (Q7-12) and old (Q7-5) GAC.

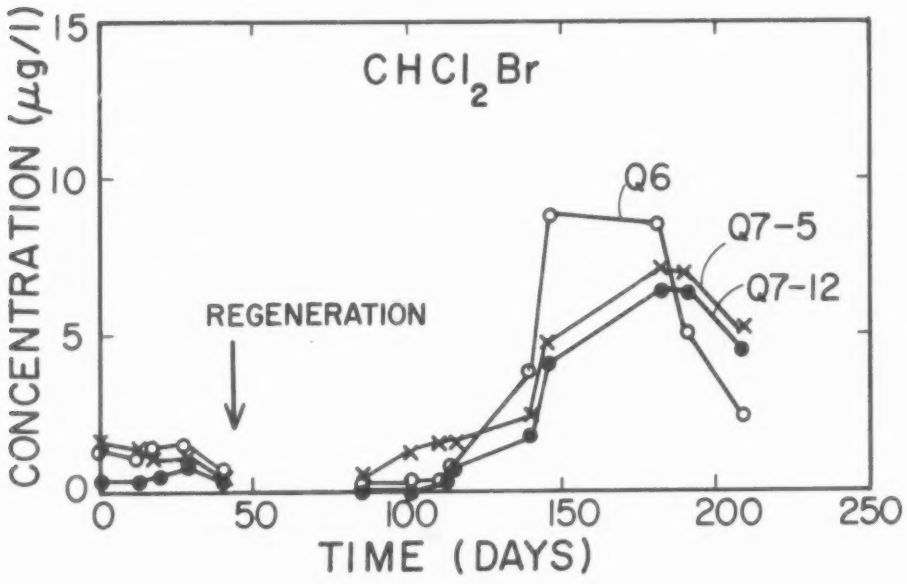


Figure 30. Comparison of bromodichloromethane removal by fresh (Q7-12) and old (Q7-5) GAC.

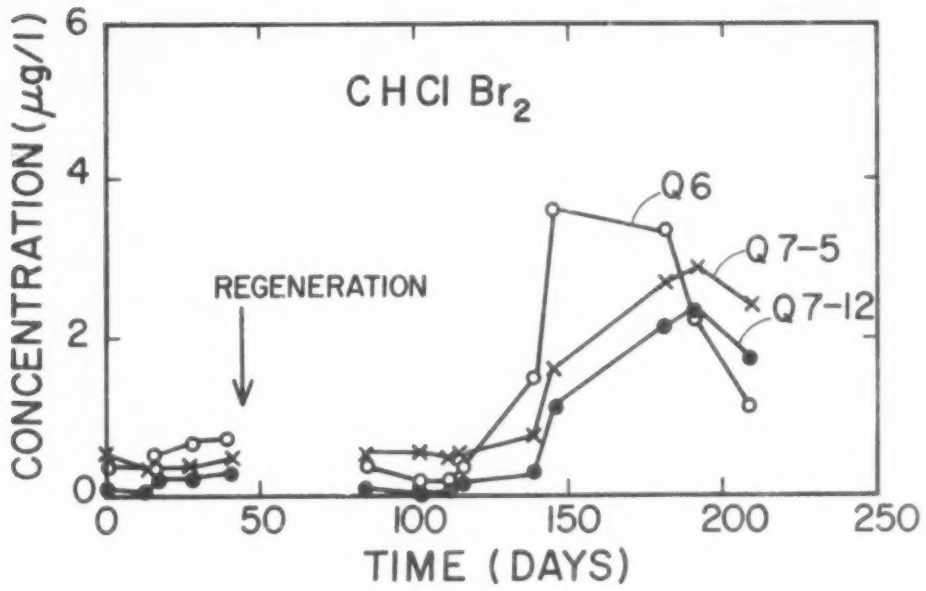


Figure 31. Comparison of dibromochloromethane removal by fresh (Q7-12) and old (Q7-5) GAC.

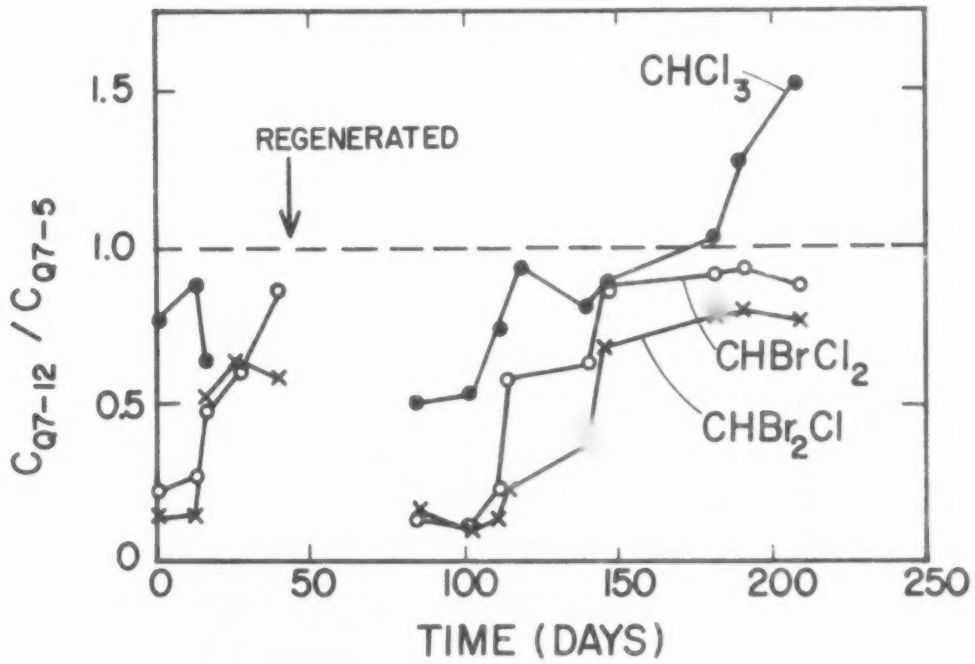


Figure 32. Ratio of effluent trihalomethane concentrations for fresh (Q7-12) and old (Q7-5) GAC.

Rationalization of Trace Organics Removal

Even though the calculated removals of the specifically measured trace organics are afflicted with wide confidence intervals and no definite relationship between structure and removal can be deducted, some trends in Tables 22 and 25 appear to be consistent. Within the group of the THMs, the removal increases with increasing number of bromines. Dichlorobenzene is better removed than chlorobenzene, and within the group of aromatic hydrocarbons, naphthalene is more efficiently removed than the xylenes and ethylbenzene. These increases in removal may be rationalized by the increase in the hydrophobicity of these compounds as measured by the n-octanol water partition coefficient, P_{oct}(11). P_{oct} increases in the sequence

$$CHCl_3 < CHBrCl_2 < CHBr_2Cl < CHBr_3$$

and also

chlorobenzene < dichlorobenzene

and

xylenes, ethylbenzene < naphthalene

This indicates that hydrophobic properties of the trace organics are directly related to their general removal by GAC even though other factors may play important roles.

The phthalate esters show an erratic behavior in such a scheme with bis-[2-ethylhexyl]-phthalate being the least removed compound of this group. This may be due in part to a lack of specificity in the analytical methods and as yet undetected interferences. The low removal and/or increase in tetrachloro-,trichloro-ethylene, and alkylated benzene concentrations is difficult to explain. These elevated concentrations may be due to leakage from the tank coating, which is known to contain tetra- and trichloroethylene. Alkylated benzenes may originate from GAC which contains aromatic hydrocarbons in its structure.

If one rank orders the efficiency of removal of THM's in the old GAC column from most efficiently removed to least removed, it is noted that this ordering is the same as for the fresh GAC, even though the absolute percent removal is different (i.e. tribromomethane is still removed to the greatest extent and chloroform to the least in both columns). The same comparison holds for the chlorobenzenes and for the aromatic hydrocarbons. This indicates that biological processes may also be important in the removal of many trace organics.

The phthalate esters again show an inconsistant behavior, which is slightly different, however, than in the fresh GAC where dimethylphthalate seems to be removed. The effluent concentrations of alkylated benzenes seem to be lower in old compared with fresh GAC, which may suggest that leakage

was reduced during prolonged use or else biological factors are important in removal.

In summary, GAC was effective in removing many trace organic materials even after it had become exhausted as measured by breakthroughs of COD and TOC. Such breakthrough occurred with about one to two months of operation after the GAC had been regenerated. Breakthrough of THM's also occurred during this period. Thus, a question remains as to the required frequency for regeneration. Based upon the results of this study, this depends upon the objective to be achieved. If GAC is being used to maintain low concentrations of THM's, COD, or TOC in the effluent, then regeneration must be done much more frequently than if the GAC is being used to remove more hydrophobic materials such as pesticides and PCB's. Thus, proper design and operation of GAC depends upon a clear understanding of the objectives to be achieved.

REVERSE OSMOSIS

Figure 11 in Section 7 indicates the distribution of COD at various sampling locations in WF-21. This Figure shows that RO is highly effective in the removal of COD. During the third period the geometric mean influent and effluent COD concentrations were 14.6 and 1.3 mg/l, respectively, for an average removal of 91 percent, with a 95% confidence interval of 89 to 92 percent.

While RO was most effective in COD removal, it was quite ineffective in the removal of trace organics. Table 26 is a summary of the percentage removals with 95 percent confidence intervals observed for the full scale reverse osmosis system and for a 55 m^3/day (10 gpm) pilot RO system employing similar RO membranes, but treating water taken from point Q2 (after chemical treatment). The full scale system was followed by a decarbonator which removed carbon dioxide from the treated water by air stripping. The percentage removals noted in Table 26 for the full scale system represent that for the reverse osmosis treatment plus decarbonation. It was determined subsequently that almost all of the removal of volatile organics including trihalomethanes, carbon tetrachloride, 1,1,1-trichloroethane, and trichloroethylene, resulted from air stripping in the decarbonator rather than from removal by reverse osmosis. The poor removal of trace organics by reverse osmosis is best indicated by the pilot RO system which did not have an air stripping system.

The trace organic materials represented in Table 26 generally have molecular weights below 200 and are nonionic. The data obtained thus indicate that nonionic low molecular weight organic materials are poorly removed by the RO membranes. However, higher molecular weight polymeric materials, which represent the majority of organics in secondary effluents as measured by the COD test, are effectively removed by RO. These higher molecular weight materials represent the class of compounds generally referred to as the humic and fulvic materials. Many of the higher molecular weight and hydrophilic materials in secondary municipal effluents are also not removed well by GAC. Thus, RO is a complimentary process to lime treatment, air stripping, and GAC.

TABLE 26. AVERAGE PERCENTAGE REMOVAL OF CONTAMINANTS BY FULL-SCALE AND PILOT RO SYSTEMS DURING THE THIRD PERIOD*

	Full Scale RO			Pilot RO		
Contaminant	Inf. Conc. (Q22A)	Eff. Conc. (Q22B)	% Removal (95% CF)	Inf. Conc. (Q21A)	Eff. Conc. (Q21B)	% Removal (95% CI)
Chloroform	7.5	1.0	87(81 to 91)	5.5	5.5	0(-51 to 34)
Bromodichloromethane	0.81	0.24	70(53 to 81)	0.87	0.95	-9(-72 to 31)
Dibromochloromethane	0.31	0.13	58(27 to 76)	8.82	0.91	-11(-41 to 13)
Tribromomethane	0.08	0.007	91(-1 to 99)	0.63	0.65	-3(-61 to 34)
Carbon tetrachloride	0.06	0.008	86(-3 to 98)	-		-
1,1,1-Trichloroethane	0.18	0.083	53(-168 to 92)	4.9	6.3	-28(-151 to 35)
Trichloroethylene				1.5	1.7	-12(-118 to 42)
Tetrachloroethylene	0.17	0.20	-18(-222 to 57)	1.5	1.8	-21(-79 to 18)
Chlorobenzene	0.04	0.034	17(-93 to 64)	0.14	0.07	49(-18 to 78)
1,2-Dichlorobenzene	-		-	0.46	0.38	17(-72 to 60)
1,3-Dichlorobenzene	-		-	0.12	0.065	46(10 to 67)
1,4-Dichlorobenzene	-		-	1.2	0.99	17(-9 to 37)
1,2,4-Trichlorobenzene	-		-	0.04	0.11	-150(-541 to 3)
Heptaldehyde	-		-	0.18	0.05	71(39 to 86)
Heptylcyanide	-		-	0.04	0.02	49(-90 to 86)
Ethylbenzene	0.02	0.02	0(-117 to 54)	0.05	0.029	44(-66 to 81)
m-Xylene	0.02	0.02	-4(-104 to 47)	0.08	0.045	45(-67 to 82)
p-Xylene	-		-	0.02	0.022	8(-236 to 75)
Naphthalene	0.02	0.03	-22(-237 to 56)	0.05	0.067	-31(-865 to 82)
1-Methylnaphthalene	-		-	0.02	0.02	5(-191 to 69)
2-Methylnaphthalene	0.02	0.008	60(-36 to 88)	0.02	0.02	-19(-264 to 61)
Styrene	-		-	0.02	0.01	44(-373 to 93)
Dimethylphthalate	2.4	1.0	58(4 to 82)	1.3	1.0	19(-47 to 56)
Diethylphthalate	-		-	0.45	0.52	-16(-168 to 50)
Di-n-butylphthalate	0.90	1.1	-22(-337 to 66)	0.69	0.73	-6(-194 to 62)
Diisobutylphthalate	0.33	0.23	30(-566 to 93)	2.9	2.5	14(-22 to 39)
Bis-[2-ethylhexyl]-phthalate	7.8	2.9	63(-109 to 93)	-		-
Lindane	-		-	0.08	0.06	27(0 to 47)
COD, mg/l	14.6	1.3	91 (89 to 92)	-		-
TOC, mg/l	7.2	2.6	64 (55 to 71)	-		-
Electrocond., µS/cm	1470	156	89 (89.1 to 90)	-		-

*Concentrations in µg/l unless otherwise shown.

The RO unit was installed primarily for removal of dissolved inorganic solids rather than organic materials. Based upon electroconductivity, 89 percent of the inorganic salts were removed by RO treatment, resulting in an effluent with an electroconductivity of 156 µS/cm. This is equivalent to an inorganic dissolved solids concentration of about 100 mg/l.

SECTION 9

PLANT RELIABILITY

THE CONCEPT OF RELIABILITY

Reliability is a measure of the degree of successful performance of a facility with respect to required conditions of operation. In order to determine the reliability of a system, one must know what it is supposed to do under all relevant conditions, and what it is likely to do under all relevant circumstances. The question then is what is the probability that the achieved performance will meet the required performance?

When the required performance is specified in a list of water quality standards, then a reliable system might be defined as one which delivers water meeting these standards close to 100 percent of the time. It would not actually be necessary to always produce water meeting the standards. The quality of treated water could be continuously monitored and only that which meets the standards could be selected for delivery. Since the demand for water is generally continuous, adequate storage or another source of water must be available so that water delivery can also be reliable. The ground water basin into which WF-21 effluent is injected meets this requirement.

Water from the treatment system need be delivered to the injection system only when it meets the required quality. This capability means that WF-21 need not function in a fail-safe mode as far as equipment or process operation is concerned. If a piece of equipment fails to operate properly, then operation of the treatment system can be stopped, or the water can be wasted without injection. Also, routine maintenance can be conducted at scheduled times of the year. Use of the storage capabilities of the ground water reservoir thus gives much flexibility to the operation of WF-21. It also helps reduce the cost of wastewater reclamation since no standby processes need be available.

Nevertheless it is desirable that WF-21 be capable of meeting water quality requirements with high frequency in order to minimize the cost of the water delivered. The reliability of a treatment system to produce water meeting given standards can be increased in several ways as indicated in Table 27. An important aspect is the improvement in the quality of the influent water, as was achieved in March 1978 when the input water to WF-21 changed from trickling filter system to an activated sludge effluent and the industrial waste contribution was reduced. These changes have had a dramatic

effect on the quality of the influent water and have increased reliability of operation considerably.

WF-21 also takes advantage of the other options listed in Table 27 for increasing reliability. The reverse osmosis system was added in 1977 in order to meet mineral requirements for injection. Also, water from a deep aquifer can be blended with WF-21 effluent to help meet mineral requirements for injection. Whenever, the given water quality criteria cannot be met, the treated water is not injected, but is wasted. Also, if necessary, the efficiency of the activated carbon process can be improved by more frequent regeneration. Thus, the combination of options indicated in Table 27 are being used at WF-21 to improve system reliability to meet water quality requirements.

TABLE 27. OPTIONS FOR INCREASING RELIABILITY TO MEET GIVEN WATER QUALITY STANDARDS

1. Improve Quality of Influent Water
2. Increase Removal Efficiency of Individual Processes
3. Add Additional Processes in Series
4. Do not use treated water when standards exceeded
5. Blend effluent with other water

RELIABILITY OF OPERATION

What is the reliability with which WF-21 produces water which meets water quality requirements? This was one of the major research objectives of this study. In anticipation of the time when direct potable reuse of reclaimed wastewaters becomes acceptable, it is desirable to know what is the performance of an advanced wastewater treatment plant with respect to the variety of organics of health concern which are present in municipal wastewaters. What is the effectiveness of each process in the removal of each contaminant, and how does the overall system improve this effectiveness? These questions are important in designing treatment systems for other wastewaters with different qualities of influent waters and with different quality requirements on the water to be delivered. This question required information on the frequency distribution of organics at different points within the treatment system as obtained in this study.

From a distribution such as that given previously in Fig. 6 for methylene chloride, an estimate can be made of the percentage of time that the concentration of the contaminant exceeds a given value. For example, Figure 6 indicates that about 5 percent of the time, the influent concentration of methylene chloride exceeded 50 µg/l. Such estimates can also be made mathematically from given values for M and S.

For example, it might be desired to determine the percentage of time that a given maximum contaminant level (MCL) is exceeded. First, the number

of standard deviations (b) that the MCL is away from M can be determined from the following relationship:

$$b = \frac{\log MCL - \log M}{\log S} \qquad (9\text{-}1)$$

A table listing the cumulative frequency function for a standardized normal distribution can then be consulted to determine the appropriate frequency value corresponding to b (3). Table 28 is a summary of a few such values of interest.

TABLE 28. RELATIONSHIP BETWEEN STANDARD DEVIATIONS ABOVE THE MEAN AND PROBABILITY OF OCCURRENCE FOR A NORMAL DISTRIBUTION

Number of Standard Deviations MCL is above Geometric Mean Concentration (b)	Percentage of Time Concentration is less than MCL
0.00	50
0.84	80
1.28	90
1.64	95
2.06	98
2.33	99
3.03	99.9

The frequency with which a given MCL or other selected value is exceeded can then readily be determined from the straight line plot of concentration distribution drawn on log probability paper, by use of values for M and S or from use of Eq. 9-1. The results of this analysis are summarized in the following.

RELIABILITY IN MEETING STATE REQUIREMENTS

The California Regional Water Quality Control Board and the State Department of Health have established requirements for injection water quality for WF-21 (Tables 29 and 30). The geometric mean concentration for all constituents was well below the specified MCL values for both periods. However, there have been some violations of the regulations at times. The number and frequency of violations are given in the last column of the two tables as the ratio of number of times the MCL was exceeded to the number of analyses which were made. The fraction so

TABLE 29. COMPARISON BETWEEN STATE SPECIFIED MCL FOR INJECTION WATER AND ACTUAL MEASURED CONCENTRATIONS DURING PERIOD TWO; OCTOBER 1976 THROUGH FEBRUARY 1978

		Injection Water (Q10)		
Contaminant	State Specified MCL	Geometric Mean Conc.	Predicted Percent of Time MCL Exceeded*	Number of Times MCL Exceeded**
Electrical Conductivity	900 µS/cm	708 µS/cm	19	31/377
Ammonium	4 mg/l	0.6 mg/l	5	5/195
Total Nitrogen	10 mg/l	1.0 mg/l	10^{-3}	0/150
Fluoride	0.8 mg/l	0.6 mg/l	3	0/50
Boron	0.5 mg/l	0.33 mg/l	12	1/56
Chromium	0.05 mg/l	0.004 mg/l	0.6	0/55
Cadmium	0.01 mg/l	0.0004 mg/l	10^{-2}	0/55
Selenium	0.01 mg/l	<0.01 mg/l	-	0/55
Copper	1.0 mg/l	0.008 mg/l	10^{-8}	0/49
Lead	0.05 mg/l	0.001 mg/l	0.1	0/48
Mercury	0.005 mg/l	0.001 mg/l	1	1/50
Arsenic	0.05 mg/l	<0.01 mg/l	-	0/49
Iron	0.3 mg/l	0.045 mg/l	0.8	0/55
Manganese	0.05 mg/l	0.004 mg/l	10^{-3}	0/55
Barium	1.0 mg/l	0.01 mg/l	10^{-9}	0/48
Silver	0.05 mg/l	0.003 mg/l	0.1	0/47
Coliforms	2.2/100 ml	0.03/100 ml	7	0/116δ
Turbidity#	1.0 TU	0.4 TU	3	4/237

*Based upon lognormal distribution model

δ Six samples exceeded 2.2/100 ml, but not in consecutive samples.

**Given as m/n where m = no. of times MCL was exceeded out of n samples analyzed.

#MCL for COD at Q8 and for turbidity at Q6.

TABLE 30. COMPARISON BETWEEN STATE SPECIFIED MCL FOR INJECTION WATER AND ACTUAL MEASURED CONCENTRATIONS DURING PERIOD THREE; MARCH 1978 THROUGH DECEMBER 1978

		Injection Water (Q10)		
Contaminant	State Specified MCL	Geometric Mean Conc.	Predicted Percent of Time MCL Exceeded*	Number of Times MCL Exceeded**
Electrical Conductivity	900 µS/cm	500 µS/cm	12	0/306
Sodium	110 mg/l	70 mg/l	21	6/31
Hardness ($CaCO_3$)	220 mg/l	64 mg/l	11	1/31
Sulfate	125 mg/l	43 mg/l	23	3/29
Chloride	120 mg/l	69 gm/l	20	5/31
Ammonium	4 mg/l	0.3 mg/l	7	0/183
Total Nitrogen	10 mg/l	0.7 mg/l	3	0/183
Fluoride	0.8 mg/l	0.57 mg/l	18	1/31
Boron	0.5 mg/l	0.38 mg/l	17	1/39
Chromium	0.05 mg/l	0.0016 mg/l	0.1	0/40
Cadmium	0.01 mg/l	0.001 mg/l	10	1/40
Selenium	0.01 mg/l	<0.005 mg/l	--	0/34
Copper	1.0 mg/l	0.012 mg/l	10^{-3}	0/39
Lead	0.05 mg/l	0.0016 mg/l	0.1	0/40
Mercury	0.005 mg/l	<0.001 mg/l	--	0/42
Arsenic	0.05 mg/l	<0.005 mg/l	--	0/32
Iron	0.3 mg/l	0.03 mg/l	0.2	0/39
Manganese	0.05 mg/l	0.003 mg/l	0.4	1/39
Barium	1.0 mg/l	0.003 mg/l	10^{-6}	0/39
Silver	0.05 mg/l	0.001 mg/l	10^{-3}	0/40
COD #	30 mg/l	12 mg/l	0.2	0/125
MBAS	0.5 mg/l	0.04 mg/l	<0.001	0/28
Cyanide	0.2 mg/l	0.002 mg/l	<0.001	0/32
Phenol	1.0 µg/l	0.6 µg/l	32	10/30
Coliforms	2.2 /100 ml	0.01/100 ml	7	10/137##
Turbidity#	1.0 TU	0.36 TU	0.5	0/275

MCL for COD at Q8 and for turbidity at Q6.

* Based on lognormal distribution model.

Ten samples exceeded 2.2/100 ml, but not in consecutive samples.

** Given as m/n where m = no. of times MCL exceeded out of n samples analyzed.

represented gives the proportion of the time for which the MCL was exceeded. In the next to the last column, a predicted percentage of the time for which the MCL would be exceeded as calculated from the lognormal distribution model (Eq. 9-1) is also given for comparison. The predicted frequency of violations and measured frequency are quite similar, indicating in general that the lognormal model is a good representation of the data.

The lognormal model, however, was not a good predictor of violation frequency for electrical conductivity, boron, and fluoride during the third period (Table 30). In these cases the electrical conductivity is continuously measured and water is not injected if the MCL is exceeded. Because of the close operational control which is possible here, the MCL for electrical conductivity need never be exceeded. The selected rejection which results disturbs the otherwise random fluctuation in data for electrical conductivity and other dissolved salts. The predicted value is perhaps a reasonable (but not accurate) indicator of the frequency with which the MCL would be exceeded if such operational control were not possible.

A review of the more complete data in Table 30 for the third period indicates that inorganic constituents such as sodium, sulfate, and chloride exceeded the State and Regional specified MCL values more than 5% of the time. These inorganic constituents are not removed by any of the advanced wastewater treatment processes except reverse osmosis. A review of the data indicates that all violations occurred when the electrical conductivity exceeded 700 µS/cm. At least one of the MCL values was exceeded about 50% of the time (8 out of 10 when the electrical conductivity exceeded this value). Thus, better conformity with the State and Regional MCL values appears possible if the electrical conductivity of the injection water is not allowed to exceed 700 µS/cm.

Another constituent which frequently exceeded the MCL was phenol. The current MCL is very near the detection limit of the analytical method. This has caused difficulty in obtaining accurate measurements for phenol, and this may be a cause for the high frequency with which this constituent appears to have exceeeded the MCL. The EPA recognized this difficulty when they dropped the phenol limit in the presently proposed National Interim Secondary Drinking Water Regulations.

The coliform concentration exceeded the specified MCL of 2.2/100 ml on occasion (10 out of 137), but did not do so in consecutive samples. Thus, the regulations for coliforms were always met.

The results in Tables 29 and 30 suggest that performance has been quite reliable for all constituents except sodium, chloride, and sulfate, salts which do not have health implications and thus are not of major importance. Performance with respect to these salts could be improved if injection water were rejected when the electrical conductivity exceeded 700 µS/cm. Operationally this is not difficult to do. A question which might be raised is whether these values are sufficiently critical to require rejection of the water, or whether modification of the specified MCL's might be appropriate.

RELIABILITY IN MEETING EPA PRIMARY REGULATIONS

While Water Factory 21 effluent is not used for direct potable purposes, a comparison of treatment results with the EPA National Interim Primary Drinking Water (NIPDW) MCL values is desirable because of interest in advanced wastewater treatment for this purpose. In this comparison, only the influent to Water Factory 21 (Table 31) and the effluent from the basic AWT plant through activated carbon adsorption and disinfection (Table 32) are considered. Table 31 indicates that in the influent the geometric mean concentrations of only cadmium, lead, coliforms, and turbidity exceeded the NIPDW MCL values. In addition, during at least 2 percent of the time, lead, mercury and fluoride exceeded the MCL values. Thus, these are the only constituents which Water Factory 21 would have to remove effectively to meet the NIPDW regulations.

TABLE 31. COMPARISON BETWEEN NATIONAL INTERIM PRIMARY DRINKING WATER (NIPDW) REGULATIONS AND INFLUENT WATER QUALITY#

		Influent Water (Q1)			
		Second Period		Third Period	
Contaminant	NIPDW MCL	Geometric Mean	98% of Time Less Than	Geometric Mean	98% of Time Less Than
Arsenic, mg/l	0.05	<0.005	<0.005**	<0.005	<0.005**
Barium, mg/l	1.0	0.08	0.14	0.03	0.06
Cadmium, mg/l	0.01	0.026	0.07	0.033	0.15
Chromium, mg/l	0.05	0.14	0.31	0.048	0.11
Lead, mg/l	0.05	0.02	0.051	0.007	0.017
Mercury, mg/l	0.002	0.0016	0.025	<0.001	?
Nitrate (as N), mg/l	10	0.23	1.2	2.8	49
Selenium, mg/l	0.01	<0.0025	<0.0025**	<0.0025	?
Silver, mg/l	0.05	0.003	0.007	0.001	0.006
Fluoride, mg/l	1.4*	1.4	2.0	1.3	1.9
Coliforms, MPN/100ml	1	89	38,000	1.6	195
Endrin, µg/l	0.2	<0.01	<0.01	<0.01	<0.01
Lindane, µg/l	4	0.2	0.9	0.14	0.22
Toxaphene, µg/l	5	<0.01	<0.01	<0.01	<0.01
2,4-D, µg/l	100	<0.01	<0.01	<0.01	<0.01
2,4,5-TP, µg/l	10	<0.01	<0.01	<0.01	<0.01
Methoxychlor, µg/l	100	<0.1	<0.1	<0.01	<0.01
Turbidity, TU	1	42	79	7	54

#Underlined values represent those exceeding MCL
* Temperature > 26.3 C°
** Based on less than 1 in 20 samples analyzed

TABLE 32. COMPARISON BETWEEN NATIONAL INTERIM PRIMARY DRINKING WATER (NIPDW) REGULATIONS AND EFFLUENT WATER QUALITY

Contaminant	NIPDW MCL	Effluent Water (Q8 or Q9) Second Period	
		Geometric Mean	98% of Time Less Than
Arsenic, mg/l	0.05	<0.005	
Barium, mg/l	1.0	0.03	0.08
Cadmium, mg/l	0.01	0.001	0.006
Chromium, mg/l	0.05	0.02	0.09
Lead, mg/l	0.05	0.002	0.036
Mercury, mg/l	0.002	0.0017	0.012
Nitrate, mg/l	10	0.4	2.4
Selenium, mg/l	0.01	<0.004	?
Silver, mg/l	0.05	0.003	0.007
Fluoride, mg/l	1.4*	0.6	1.2
Coliforms, MPN/100 ml	1	0.01	14
Endrin, µg/l	0.2	<0.01	<0.01
Lindane, µg/l	4	<0.05	<0.05
Toxaphene, µg/l	5	<0.01	<0.01
2,4,5-TP, µg/l	10	<0.01	<0.01
Methoxyclor, µg/l	100	<0.1	<0.1
Turbidity, µg/l	1	0.4	1.1

#Underlined values represent those exceeding MCL

*Temperature > 26.3 °C

Table 32 indicates that the geometric mean concentration of all contaminants in the effluent from AWT treatment (Q8 or Q9) met the NIPDW requirements. Also, during the second period, only chromium and mercury did not meet the requirements more than 98 percent of the time. Lognormal probability plots for cadmium and chromium during the second period are shown in Figures 22 and 23, Section 8, and are based upon the calculated values for M and S at various sampling locations. Figure 22 indicates that lime treatment was most effective in removing cadmium, bringing the concentration well below the MCL at the Q2 sampling point. Figure 23 also indicates that lime treatment was efficient in removing chromium, although not sufficiently to meet the MCL. Activated carbon adsorption (between points Q6 and Q8) also was beneficial, so that in the AWT effluent (Q9) the MCL was exceeded only about 10 percent of the time.

RELIABILITY FOR REMOVING ORGANIC MATERIALS

Current drinking water regulations cover few organic materials, such as the pesticides listed in Tables 31 and 32 and a current proposed MCL of 100 µg/l for trihalomethanes (6). However, there is concern over other trace organic substances which might be present in wastewaters reclaimed for potable use. Thus, there is a need for information on organic materials in reclaimed water.

Figure 11, Section 7, shows the distribution of COD at various sampling locations at WF-21 during the third period of operation. It is evident that several processes are effective in removing COD including lime treatment, activated carbon adsorption (between Q6 and Q8), and RO treatment. While the latter process is expensive, the result is water having a geometric mean COD concentration of about 2 mg/l, (equivalent to about 0.8 mg/l organic carbon) which is as low a value as found in many water supplies in the United States (12).

Table 33 is a summary of the percent probability of water meeting various COD concentrations after different stages of treatment. At Water Factory 21, the COD after activated carbon treatment (Q8) must be less than 30 mg/l, and in current operation this is reached 99.8 percent of the time. It is also met by chemical treatment 82 percent of the time and subsequent filtration increases this to 96 percent of the time. The current COD requirement can thus be met with high reliability. However, stricter COD requirement, say 10 mg/l, would necessitate more frequent regeneration of activated carbon or addition of other unit processes.

TABLE 33. PROBABILITY IN PERCENT OF MEETING VARIOUS HYPOTHETICAL COD CRITERIA AT DIFFERENT SAMPLING POINTS AT WATER FACTORY 21 DURING THE THIRD PERIOD

	Hypothetical COD Criteria				
Sampling Point	2 mg/l	5 mg/l	10 mg/l	20 mg/l	30 mg/l
Q1 - Plant Influent	0.0	0.0	0.0	0.0	1.0
Q2 - Lime Effluent	0.0	0.0	0.0	0.5	82
Q6 - Filter Effluent	0.0	0.0	0.0	9.2	96
Q8 - Act. Carb. Effluent	0.0	0.2	25	94	99.8
Q22B - RO Effluent	69	95	99.8	99.97	>99.99
Q10 - Inject. Water	1.2	35	85	99.3	99.9

While MCLs for most trace organics have not been established, it is useful to pose hypothetical values in order to determine which compounds or classes of compounds may present the most difficulty in meeting potable reuse regulations should they eventually be developed. In order to do this, hypothetical MCL values which are probably below concentrations which would cause a health effect were chosen. The hypothetical MCLs are 1 µg/l for the non-chlorinated trace organics and 0.5 µg/l for the chlorinated trace organics. These values are significantly below all NIPD MCL values for pesticides except endrin.

Tables 34 and 35 indicate the percentage of time the influent and effluent waters from WF-21 exceeded these hypothetical MCL values during the second and third periods at WF-21. During the second period, all of the organics exceeded the hypothetical MCL in the influent more than 10 percent of the time, while during the third period only about onehalf did. This illustrates an advantage of efficient biological treatment and segregation of industrial wastes prior to advanced treatment. The data in Table 35 indicate that after treatment through activated carbon adsorption and disinfection (Q9) during the third period, only some of the chlorinated methanes and ethanes, and some of the phthalates exceeded the hypothetical MCL values more than 10 percent of the time. It is interesting to note that reverse osmosis was of little help in removing these compounds. The chlorobenzenes, aromatic hydrocarbons, and pesticides were all efficiently and reliably removed by treatment.

The chlorinated methanes and ethanes are common solvents and appear to present a special problem. They were removed most effectively by air stripping, even during the third period when forced air circulation was not used in the stripping towers. However, during subsequent treatment, contamination frequently resulted. These materials are generally used in solvents, paints, and coatings. Occasional increased concentrations at different points in the treatment plant may have resulted from use of materials containing organic solvents during normal plant maintenance. This needs further investigation. The phthalates are commonly used as plasticizers and can be leached from plastic pipe. It is also difficult to keep samples from becoming contaminated with phthalates after collection so that reliable analysis is difficult. Thus, if actual standards near the hypothetical MCL values for these materials are proposed, then greater care would be needed in the selection of materials for treatment plant process coatings and pipe lines, of materials used in normal plant maintenance, and of sampling and analytical procedures.

SUMMARY AND DISCUSSION

This study has shown that a full scale advanced wastewater treatment system was capable of good reliability in the removal of many contaminants from biologically treated municipal wastewater. Reliability at WF-21 is increased through the operating philosophy which has

TABLE 34. PERCENTAGES OF TIME HYPOTHETICAL MCLS FOR VARIOUS TRACE ORGANICS WERE EXCEEDED DURING SECOND PERIOD

Contaminant	Hypothetical MCL µg/l	Geometric Mean Influent Conc. µg/l	Percent of Time Hypothetical MCL Exceeded		
			Influent Q1	AWT Effluent Q9	RO Effluent Q21B
Methylene Chloride	0.5	17	99.99	82	-
1,1,1-Trichloroethane	0.5	4.7	98	6	-
Trichloroethylene	0.5	0.9	67	5	-
Tetrachloroethylene	0.5	0.6	54	21	-
Chlorobenzene	0.5	2.5	95	1	0.4
1,2-Dichlorobenzene	0.5	2.4	96	5	10^{-7}
1,3-Dichlorobenzene	0.5	0.7	61	6	10^{-4}
1,4-Dichlorobenzene	0.5	2.1	95	15	0.2
1,2,4-Dichlorobenzene	0.5	0.5	48	6	-
Ethylbenzene	1.0	1.4	63	0.2	10^{-4}
Napthalene	1.0	0.6	28	10^{-3}	0.2
1-Methylnapthalene	1.0	0.9	42	10^{-6}	0.7
2-Methylnapthalene	1.0	1.0	50	0.5	2.5
Dimethylphthalate	1.0	16	100	79	-
Di-n-butylphthalate	1.0	<0.5	-	20	87
Diisobutylphthalate	1.0	2.9	86	42	100
Bis-[2-ethylhexyl]-phthalate	1.0	28	100	85	86
PCB as Aroclor 1242	0.5	3.3	99.9	<12	<20
Lindane	0.5	0.2	10	<12	<20

been adopted. This plant is operated under a constant flow condition so that hydraulic fluctuations are eliminated. Significant removal of industrial wastes from municipal sewage and efficient biological treatment of wastewaters prior to advanced wastewater treatment has had major effects in reducing the concentratration of some of the contaminants of concern, thus enhancing the reliability for meeting the treated water requirements. WF-21 can be shut down when poor quality water is received or when desirable for routine maintenance because water need not be injected continuously for maintenance of the seawater barrier system. This increases the flexibility of operation considerably and enhances reliability in the delivery of water meeting given water quality requirements.

TABLE 35. PERCENTAGE OF TIME HYPOTHETICAL MCL VALUES FOR VARIOUS TRACE ORGANICS WERE EXCEEDED DURING THE THIRD PERIOD

Contaminant	Hypothetical MCL µg/l	Geometric Mean Influent Conc. µg/l	Percent of Time Hypothetical MCL Exceeded		
			Influent Q1	AWT Effluent Q9	RO Effluent Q22B
Carbon tetrachloride	0.5	0.03	0.1	6	5
1,1,1-Trichloroethane	0.5	3.2	92	33	28
Trichloroethylene	0.5	0.74	40	<7	<4
Tetrachloroethylene	0.5	1.7	92	27*	17
Chlorobenzene	0.5	0.14	8	2	0.8
1,2-Dichlorobenzene	0.5	0.64	60	0.03	0.8
1,3-Dichlorobenzene	0.5	0.16	8	<3	0.1
1,4-Dichlorobenzene	0.5	1.8	99.5	1	0.03
1,2,4-Trichlorobenzene	0.5	0.11	12	<3	<6
Heptaldehyde	1.0	0.1	1	2	-
Heptylcyanide	1.0	0.002	0.2	0.1	-
Ethylbenzene	1.0	0.04	0.4	10^{-5}	10^{-5}
m-Xylene	1.0	0.04	0.003	0.003	0.002
p-Xylene	1.0	0.02	10^{-8}	10^{-10}	10^{-9}
Napthalene	1.0	0.03	0.2	0.001	0.001
1-Methylnapthalene	1.0	0.01	10^{-5}	<3	0.8
2-Methylnapthalene	1.0	0.01	0.1	<3	10^{-5}
Styrene	1.0	0.05	0.1	0.5	-
Dimethylphthalate	1.0	4.8	99	26	50
Diethylphthalate	1.0	0.10	15	<4	<8
Di-n-butylphthalate	1.0	0.79	39	14	56
Diisobutylphthalate	1.0	4.7	99.7	21	25
Bis-[2-ethylhexyl] phthalate	1.0	11	99.9	>99.9	85
PCB as Aroclor 1242	0.5	0.47	45	<5	<7
Lindane	0.5	0.14	10^{-7}	<5	<8

*Based upon concentration at Q8, values at Q9 were higher due to leaching from coating on chlorine contact basin.

Another factor affecting reliability is the physical-chemical (rather than biological) system. Little time is required to adjust plant operating conditions properly after starting or stopping, or whenever desirable. In addition, the groundwater basin itself enhances the reliability of this type of system. The aquifer represents a very large underground storage reservoir. As the reclaimed water travels from the injection point through layers of clay and sand, some constituents may

be removed from the water, which is ultimately withdrawn at points several hundreds of meters from the injection point. Other constituents will alternately adsorb and desorb, and by this process the effects of any peak concentrations will be evened out as the water moves through the groundwater system (13). For this reason, occasional maximum values which exceed requirements may not be as important as average values. Thus, the mean values could possibly be more meaningful than extremes in reclaimed effluents used for groundwater injection. These considerations should be carefully evaluated before facilities for potable reuse of municipal wastewaters are designed.

Finally, a note of caution must be expressed when considering the limited analysis presented here in relation to direct reuse for potable purposes. While the distribution of concentrations for many trace materials have been quantified in this study, a large fraction of the organic carbon remains yet uncharacterized. The possible health significance of these materials still needs to be evaluated before direct reuse of municipal wastewater for potable purposes can be implemented.

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APPENDIX A

MAJOR DESIGN CRITERIA FOR 0.66 m^3/s ADVANCED WASTEWATER TREATMENT PLANT

INFLUENT PUMP STATION

Number of pumps:	2
Capacity:	0.41 m^3/s @ 8.8 m TDH, 0.44 m^3/s @ 8.2 m TDH
Type:	Vertical mixed flow

CHEMICAL CLARIFICATION SYSTEM

Rapid Mixing

Number of basins:	2 in series; mechanical mixer in each basin
Dimension:	Length, 3.7 m; width, 3.7 m; depth, 3.7 m
Detention time:	2.4 minutes total @ 0.66 m^3/s
Chemical addition:	First basin, lime alum, recycled lime sludge; second basin, polymer

Flocculation

Number of basins:	2, three compartments each
Detention time:	10 min/compartment (30 min total) @ 0.66 m^3/s
Chemical addition:	Polymer, 1st and 3rd compartment
Dimensions:	Length, 15 m; width, 12.5 m; depth, 3.4 m
Flocculator mechanism:	Oscillating type

Settling Basin

Number of basins:	2 rectangular
Dimensions:	37 m long x 12 m wide, each
Surface overflow rate:	2.7 m^3/m^2-hr @ 0.66 m^3/s
Each basin equipped with settling tubes	

Clarifier Effluent Pump Station

Number of pumps:	4
Capacity:	0.21 m^3/s @ 23 m; 0.22 m^3/s @ 20 m
Discharge:	To air stripping tower or to the OCSD plant or to the recarbonation basins

Lime Feeders and Slakers

Number: 2 gravimetric feeders and paste-type slakers
Capacity: 0.5 kg/s

Polymer Feed System

Number of mixing tanks: 2 (4 m^3 each)
Number of feed pumps: 4 dual head
Capacity: 0 to 0.1 m^3/h each head

Alum Feed System

Number of storage tanks: 2 (18 m^3 each)
Number of feed pumps: 3 (2 double head and 1 single head)
Capacity: 0.1 m^3/h each head

AIR STRIPPING/COOLING TOWERS

Number of towers: 2
Dimensions: Length, 63 m; width, 19 m; depth of packing, 7.6 m
Capacity: 0.33 m^3/s each @ 0.44 m^3/m^2-min
Number of fans: 6 per tower, 5.5 m diameter, 2-speed electric motors
Air capacity: 990 m^3/s per tower (3000 m^3/m^3)
Net water streams: Tower No. 1, 0.50 m^3/s cool 46°C to 26°C
Tower No. 2, 0.69 m^3/s cool 50°C to 30°C

RECARBONATION

Number: Two 3-compartment basins, originally designed for two-stage recarbonation but always used as one-stage recarbonation basin
Detention time: 30 minutes (15 min. each basin)
Overflow rate, intermediate settling: 5 m^3/m^3-h @ 0.66 m^3/s

FILTRATION

Number of filters: 4
Dimensions: 6.7 m x 7.3 m
Type: Open, gravity, mixed media
Hydraulic loading rate: 0.2 m^3/m^2-min @ 0.66 m^3/s
Maximum operating head loss: 3 m
Filter aids: Alum and polymers
Backwash system: Hydraulic with rotating surface wash arms. Backwash rate, 0.6 m^3/m^2-min; surface wash rate, 0.024 m^3/m^2-min
Backwash water receiving tank volume: 705 m^3

ACTIVATED-CARBON ADSORPTION

Number of contactors:	17
Normal service:	16 in parallel operation, 1 for carbon storage and standby service
Type:	Countercurrent, in steel pressure vessels, upflow during first and second periods, but downflow during third period
Dimensions:	Overall height, 12.5 m; sidewall height, 7.3 m; diameter, 3.7 m
Contact time:	34 minutes at 0.66 m^3/s
Carbon size:	8 x 30 mesh (Filtrasorb 300, bulk density - 420 kg/m^3)
Carbon weight:	35 Mg per contactor (660 Mg total)

CHLORINATION

Number of contact basins: 1
In-line feeding and mixing
Contact time: 30 minutes
Chlorine feeders: 3 (900 kg/day each)
On-site generation of chlorine: 900 kg/day

CHEMICAL SLUDGE TREATMENT AND RECOVERY SYSTEMS

Sludge Pumps

Number:	3
Capacity:	0.032 to 0.044 m^3/s
Influent solids capability:	5% maximum

Sludge Thickener

Number:	1
Dimensions:	14 m diameter, 2.5 m sidewater depth
Loading:	24 m^3/m^2-d @ 1.5% solids from clarifier at flow of 0.66 m^3/s; dry solids loading = 15 kg/m^3-h
Thickened sludge concentration:	8 to 15% solids

Thickened Sludge Pumps

Number:	3
Capacity:	5 liter/m at 18 m head each, variable speed
Influent solids capability:	18% maximum

Centrifuges

Number:	2
Capacity:	900 kg/hour each
Feed rate:	3 to 6.6 liters/m

Recalcining Furnace

Number:	1, 6 hearth
Dimensions:	6.8 m OD; 6.1 m ID
Capacity:	0.1 to 0.5 kg/s dry CaO
Scrubber:	3-stage jet impingement
Fuel:	Natural gas with propane standby

Lime Storage Bins

Number:	2
Capacity:	32 Mg each
Dimensions:	3.8 m diameter by 4.6 m storage depth (overall height = 8.7 m)

Carbon Dioxide Compressors

Number:	3
Capacity:	0.76 m^3/s (12% CO_2) each

ACTIVATED CARBON REGENERATION

Regeneration Furnace

Number of furnaces:	1, 6 hearth
Dimensions:	2.8 m OD; 2.1 m ID
Capacity:	0.01 to 0.063 kg/s (dry basis)
Steam addition:	No. 4 and No. 6 hearths (optional); 1 kg steam per kg carbon
Air pollution control:	
Fuel:	Natural gas with propane standby
Scrubber:	Venturi followed by water separator
Afterburner:	Vertical, refractory lined steel, 760°C at 0.5 seconds minimum gas retention time

Carbon Wash and Transfer Tanks

Number:	2
Dimensions:	1.5 m diameter by 3 m high
Equipped with bag dump and dust collector	

Regenerated Carbon Wash Tanks

Number:	2
Dimensions:	1.5 m diameter by 3 m high

Spent Carbon Dewatering Tanks

Number:	2 (open top)
Dimensions:	1.5 m x 1.5 m x 4.4 m high
Furnace feed system:	0.3 m diameter screw conveyor, stainless steel with capacity of 0.01 to 0.063 kg/s on a dry basis

Carbon Slurry Pumps (transfer carbon from regeneration furnace to carbon wash tanks)

Number:	2
Type:	Diaphragm slurry, air operated, 7.6 cm suction and discharge
Capacity:	0.03 m^3/s max. with 4:1 turndown ratio

APPENDIX B

MAJOR DESIGN CRITERIA FOR 0.22 m^3/s REVERSE-OSMOSIS PLANT

GENERAL PERFORMANCE REQUIREMENTS

Minimum permeate flow rate:	0.22 m^3/s
Maximum concentrate flow rate:	0.04 m^3/s
Feed flow rate:	0.26 m^3/s
Design feed water temperature:	18°C
Annual throughput requirement:	6.4×10^6 m^3
Minimum permeate water recovery:	85%
Minimum salt rejection:	90%
Concentrate pH:	5.0 to 8.0
Permeate pH:	6.5 to 8.0
Contract completion time:	670 calendar days
Maximum noise level outside RO building:	55 db_a

PRE-TREATMENT

Feed Water Source

Normal:	Activated-carbon adsorption effluent
Optional:	Mixed-media-filtration effluent

Filter Feed Pumps

Type:	Vertical turbine, single stage
Number:	3 (includes 1 standby)
Capacity:	0.13 m^3/s
TDH:	18 m
Power:	37 kW each

Scale-Inhibitor Feeder

Number:	1
Design rate:	1.9 kg/hr (2 mg/l)
Maximum capacity:	10 kg/hr (10.5 mg/l)
Inhibitor:	Sodium hexametaphosphate

Chlorinators

Number:	1
Capacity:	230 kg/d (10.2 mg/l)
Note:	Backup to this unit from Water Factory 21 chlorinators

Feed Clearwell

Number: 1
Total capacity: 57 m^3
Average detention time at 0.26 m^3/s: 3.67 min

RO Flow Rates

Feed flow: Per section, 0.043 m^3/s; per unit, 0.13 m^3/s; total plant, 0.26 m^3/s
Permeate flow: Per section, 0.037 m^3/s; per unit, 0.11 m^3/s; total plant, 0.22 m^3/s
Concentrate flow: Per section, 0.0064 m^3/s; per unit, 0.019 m^3/s; total plant, 0.039 m^3/s

POST-TREATMENT

Decarbonators

Number: 2 (both normally in operation)
Type: Countercurrent packed bed
Air flow rate: 22 m^3/m^3
Hydraulic loading: 25 m/min

Permeate Clearwell

Number: 1
Total capacity: 34 m^3
Average detention time at 0.22 m^3/s: 2.55 min

Permeate Pumps

Type: Vertical turbine, single stage
Number: 3 (includes 1 standby)
Capacity: 0.11 m^3/s
TDH: 7.6 m
Power: 15 kW each

ELECTRICAL ENERGY REQUIREMENTS

Voltage	Total Installed (kW)
2300	2000
480	250
Total	2250

Cartridge Filters

Number: 4 (includes 1 standby)
Elements: 240 250-mm or 120 500-mm polypropylene cartridges per filter
Rating: 25 μm

RO Feed Pumps Clearwell

Number:	1
Total capacity:	128 m^3
Average detention time at 0.26 m^3/s:	825 min

RO Feed Pumps

Type:	Vertical turbine, 17 stages
Number:	3 (includes 1 standby)
Capacity:	0.13 m^3/s
TDH:	420 m, maximum; 280 m, normal
Power:	670 kW each

Acid Feeders

Acid:	Concentrated sulfuric acid (93% or 66°Be')
pH;	RO feed adjusted to pH 5.5
Type:	Positive displacement
Number:	3 (includes 1 standby)
Capacity:	0.66 liters/ min each, design; 1.3 liters/min each, maximum

REVERSE OSMOSIS

RO Membranes, Sections, Units

Number of units:	2 (both normally in operation)
Number of sections:	3 per unit
Number of pressure vessels:	35 per section
Number of membranes:	6 per pressure vessel
Total number of:	Units, 2; sections, 6; pressure vessels, 210; membranes, 1260
Pressure vessel array per section:	20 - 10 - 5
Pressure vessel length:	6.7 m
Nominal pressure vessel diameter:	200 mm
Membrane diameter:	200 mm
Membrane length:	1 m
Membrane type:	Spiral wound, cellulose acetate

SUPPORT SYSTEMS

Air Compressors

Number:	2 (includes 1 standby)
Capacity:	0.62 m^3/min
TDH:	8.8 kg/cm^2
Power:	5.6 kW

Cleaning System

Tanks:	2 at 5.7 m^3 each
Pumps:	2 at 0.055 m^3/s each, 28 m TDH, 22 kW each

Flushing System

Tanks:	2 at 25 m^3 each
Pumps:	2 at 0.019 m^3/s each, 30 m TDH, 11 kW each

APPENDIX C

SECOND-PERIOD ORGANIC DATA SUMMARY

TABLE C-1. CONCENTRATION IN µg/1 OF VOA CONSTITUENTS DURING THE SECOND PERIOD

A. Sampling Locations Q1, Q2, Q4, and Q6

Constituent	Parameter	Plant Influent Q1	Chem. Effluent Q2	Strip. Effluent Q4	Filt. Effluent Q6
		Oct.1976-Mar.1978	Oct.1976-Mar.1978	Oct.1976-Mar.1978	Oct.1976-Mar.1978
Chloroform	M	1.6	1.09	0.18	8.45*
	95%CI	1.2-2.0	0.5-2.2	0.1-0.2	4.2-17.1
	S	2.50	2.14	1.87	6.62
	N	52	7	29	32
	Nu	52	7	29	30
	R	0.2-39	0.3-2.3	0.1-0.5	<0.1-97
Bromodi-chloro-methane	M	0.09	0.21	0.08	4.82
	95%CI	0.05-0.17	0.01-7	0.01-0.5	2.7-8.6
	S	4.2	4.22	2.09	4.21
	N	42	6	5	33
	Nu	23	3	3	26
	R	<0.1-1.1	<0.1-1.4	<0.1-0.2	<0.1-32
Dibromo-chloro-methane	M	0.15	<0.1	0.10	1.44
	95%CI	0.05-0.46	-	0.01-1	0.7-3.1
	S	12.6	-	2.85	5.77
	N	35	6	4	29
	Nu	22	1	3	23
	R	<0.1-10	<0.1-0.2	<0.1-0.3	<0.1-18
Tribromo-methane	M	0.12	<0.1		0.15
	95%CI	0.03-0.5	-		0.02-1.5
	S	8.1	-		15.7
	N	24	5		19
	Nu	11	0		8
	R	<0.1-3	<0.1		<0.1-23

*Poor lognormal fit - exceeds 10% K-S boundary (normal fit okay).

(TABLE C-1A CONT.)

TABLE C-1A CONT.

Constituent	Parameter	Plant Influent Q1 Oct.1976-Mar.1978	Chem. Effluent Q2 Oct.1976-Mar.1978	Strip. Effluent Q4 Oct.1976-Mar.1978	Filt. Effluent Q6 Oct.1976-Mar.1978
Methylene chloride	M	17			1.5
	95%CI	13-23			0.9-2.3
	S	2.57			4.4
	N	41			38
	Nu	41			37
	R	1.7-74			<0.2-18
1,1,1-Trichloroethane	M	4.7	0.94	0.09	0.018
	95%CI	3.5-6.3	0.1-11	0.02-0.3	0.002-0.1
	S	2.86	10.1	7.55	7.14
	N	50	7	17	30
	Nu	47	6	12	6
	R	<0.3-38	<0.1-28	<0.1-2.5	<0.1-1.2
Trichloroethylene	M	0.9	0.21	0.013	0.002
	95%CI	0.6-1.4	0.02-2.0	10^{-4}-0.4	10^{-6}-1
	S	3.9	6.06	15.8	210
	N	46	7	16	29
	Nu	41	5	5	5
	R	<0.1-12	<0.1-2.4	<0.1-1.4	<0.1-2.4
Tetrachloroethylene	M	0.6	0.16	<0.1	0.036
	95%CI	0.3-1.1	0.04-0.7	-	0.01-0.1
	S	5.8	3.30	-	7.70
	N	39	6	3	28
	Nu	31	5	1	11
	R	<0.1-15	<0.1-0.8	<0.1-0.2	<0.1-2.0

B. Sampling Locations Q8, Q9, Q21A, and Q21B

Constituent	Parameter	GAC Effluent Q8	Final Effluent Q9	R.O. Influent Q21A*	R.O. Effluent Q21B*
		Oct.1976-Mar.1978	Oct.1976-Mar.1978	Jan.1977-June 1978	Jan.1977-June 1978
Chloroform	M	6.7	7.3	1.31	4.48
	95%CI	4.7-9.5	5.8-9.2	0.1-18.1	1.8-10.9
	S	2.87	2.3	12.2	4.98
	N	34	51	6	15
	Nu	34	51	6	15
	R	0.3-36	0.8-40	0.1-21	0.1-35
Bromodi-chloro-methane	M	1.34	2.1	2.04	1.42
	95%CI	0.9-1.9	1.6-2.9	0.1-60	0.4-5.3
	S	2.96	2.9	8.35	7.96
	N	34	51	4	15
	Nu	33	50	4	12
	R	<0.1-10	<0.1-14	<0.1-23	<0.1-22
Dibromo-chloro-methane	M	0.23	0.78	0.31	
	95%CI	0.1-0.5	0.52-1.2	10^{-4}-10^{3}	
	S	4.71	3.8	25.0	
	N	25	49	4	
	Nu	22	43	3	
	R	<0.1-3.5	<0.1-10	<0.1-7.9	
Tribromo-methane	M	0.17	0.17	-	1.19
	95%CI	0.003-10	0.08-0.35	-	0.05-29.0
	S	5.08	4.7	-	3.62
	N	4	32	1	3
	Nu	3	20	1	3
	R	<0.1-0.9	<0.1-2.2	0.4	0.3-2.8
Methylene chloride	M		1.6		
	95%CI		1.1-2.3		
	S		3.6		
	N		40		
	Nu		40		
	R		0.2-33		
1,1,1-Tri-chloro-ethane	M	0.08	0.07	<0.1	0.17
	95%CI	0.01-0.5	0.04-0.13	-	10^{-5}-10^{3}
	S	4.41	3.5	-	2.55
	N	12	51	3	2
	Nu	8	17	0	2
	R	<0.1-0.5	0.1-1.2	<0.1	0.1-0.3

(TABLE C-1B CONT.)

TABLE C-1B CONT.

Constituent	Parameter	GAC Effluent Q8 Oct.1976-Mar.1978	Final Effluent Q9 Oct.1976-Mar.1978	R.O. Influent Q21A* Jan.1977-June 1978	R.O. Effluent Q21B* Jan.1977-June 1978
Trichloro-ethylene	M	0.057	0.02	<0.1	0.04
	95%CI	0.03-0.1	0.004-0.1	-	10^{-6}-10^{3}
	S	2.01	6.7	-	3.12
	N	17	48	3	7
	Nu	6	8	0	2
	R	<0.1-0.2	<0.1-1.7	<0.1	<0.1-0.2
Tetrachloro-ethylene	M	0.01	0.05	<0.1	1.15
	95%CI	10^{-3}-0.2	0.01-0.19	-	0.2-7.7
	S	10.1	17	-	9.76
	N	21	50	4	8
	Nu	5	20	1	8
	R	<0.1-0.9	<0.1-26	<0.1-0.1	<0.1-17

*Pilot reverse osmosis unit.

TABLE C-2. CONCENTRATION IN µg/l OF CLSA CONSTITUENTS DURING THE SECOND PERIOD

A. Sampling Locations Q1, Q2, Q4, and Q6

Constituent	Parameter	Plant Influent Q1	Chem. Effluent Q2	Strip. Effluent Q4	Filt. Effluent Q6
		Oct.1976-Mar.1978	Oct.1976-Mar.1978	Oct.1976-Mar.1978	Oct.1976-Mar.1978
Chloro-benzene	M	2.5	3.0	0.11	0.092
	95%CI	1.4-4.3	1.2-7.7	0.04-0.3	0.05-0.2
	S	2.6	1.81	2.67	1.84
	N	14	4	6	7
	Nu	14	4	6	7
	R	0.2-9.4	0.16-0.65	0.02-0.24	0.04-0.21
1,2-Di-chloro-benzene	M	2.4	1.2	0.18	0.17
	95%CI	1.5-4.0	0.2-6.6	0.03-1.2	0.03-0.9
	S	2.5	2.92	4.53	6.38
	N	15	4	6	7
	Nu	15	4	5	7
	R	0.3-8.9	0.38-3.2	0.01-0.75	0.01-1.2
1,3-Di-chloro-benzene	M	0.68	0.12	0.020	0.010
	95%CI	0.4-1.3	0.01-1.1	0.002-0.2	10^{-5}-4
	S	3.1	3.97	2.62	11.4
	N	15	4	6	6
	Nu	15	4	3	3
	R	0.2-1.7	0.03-0.53	<0.01-0.06	0.01-0.16
1,4-Di-chloro-benzene	M	2.1	1.02	0.029	0.024
	95%CI	1.3-3.4	0.4-2.7	0.01-0.2	0.004-0.1
	S	2.4	1.83	2.87	4.29
	N	15	4	6	6
	Nu	15	4	4	5
	R	0.8-9.2	0.51-1.9	<0.01-0.12	<0.01-0.2
1,2,4-Tri-chloro-benzene	M	0.46	0.22	0.11	0.019
	95%CI	0.2-1.1	0.02-2.0	0.004-3	10^{-8}-10^{4}
	S	4.5	2.44	3.81	4.39
	N	15	4	5	5
	Nu	13	3	3	2
	R	<0.01-4.1	<0.01-0.5	<0.01-0.6	<0.01-0.11
Ethyl-benzene	M	1.4	0.23	0.10	0.055
	95%CI	0.8-2.6	0.07-0.8	0.02-0.5	0.04-0.08
	S	2.7	1.62	4.49	1.56
	N	13	3	6	7
	Nu	13	3	6	7
	R	0.2-8.7	0.16-0.37	0.02-1.4	0.03-0.1

(TABLE C-2A CONT.)

TABLE C-2A CONT.

Constituent	Parameter	Plant Influent Q1 Oct.1976-Mar.1978	Chem. Effluent Q2 Oct.1976-Mar.1978	Strip. Effluent Q4 Oct.1976-Mar.1978	Filt. Effluent Q6 Oct.1976-Mar.1978
Naphthalene	M	0.57	0.21	0.18	0.091
	95%CI	0.3-1.0	0.04-1.1	0.07-0.5	0.02-0.4
	S	2.6	2.83	2.40	4.34
	N	16	4	6	6
	Nu	16	4	6	6
	R	0.1-4.1	0.09-0.82	0.04-0.5	0.01-0.30
1-Methyl-naphthalene	M	0.86			
	95%CI	0.5-1.4			
	S	2.1			
	N	11			
	Nu	11			
	R	0.1-3.9			
2-Methyl-naphthalene	M	1.0			
	95%CI	0.6-1.7			
	S	2.1			
	N	10			
	Nu	10			
	R	0.4-2.6			

B. Sampling Locations Q9, Q22B, and Q21B

Constituent	Parameter	Final Effluent Q9 Oct.1976-Mar.1978	R.O. Effluent Q22B Nov.1977-Mar.1978	R.O. Effluent Q21B* Jan.1977-June 1977
Chlorobenzene	M	0.05	0.16	0.043
	95%CI	0.03-0.08	0.10-0.25	0.01-0.2
	S	2.7	1.51	3.71
	N	23	6	6
	Nu	20	6	5
	R	<0.02-0.37	0.11-0.29	<0.01-0.15
1,2-Dichlorobenzene	M	0.03	0.03	0.034
	95%CI	0.01-0.08	0.02-0.05	0.01-0.2
	S	5.7	1.6	4.04
	N	23	6	6
	Nu	15	5	5
	R	<0.02-0.9	<0.02-0.05	<0.01-0.2
1,3-Dichlorobenzene	M	0.01	0.04	
	95%CI	0.001-0.07	0.02-0.07	
	S	12	1.74	
	N	22	6	
	Nu	9	6	
	R	<0.01-0.61	0.02-0.08	
1,4-Dichlorobenzene	M	0.02	0.01	0.014
	95%CI	0.003-0.14	0.000-0.24	10^{-3}-0.4
	S	21	3.6	3.81
	N	23	6	4
	Nu	12	3	3
	R	<0.02-2.41	<0.01-0.04	<0.01-0.06
1,2,4-Trichlorobenzene	M	0.01		
	95%CI	0.002-0.06		
	S	13		
	N	23		
	Nu	10		
	R	<0.01-0.5		
Ethylbenzene	M	0.03	0.05	0.022
	95%CI	0.02-0.05	0.03-0.10	0.01-0.07
	S	3.0	1.9	2.55
	N	24	6	6
	Nu	24	6	5
	R	<0.01-0.18	0.02-0.11	<0.01-0.06

(TABLE C-2B CONT.)

TABLE C-2B CONT.

Constituent	Parameter	Final Effluent Q9 Oct.1976-Mar.1978	R.O. Effluent Q22B Nov.1977-Mar.1978	R.O. Effluent Q21B* Jan.1977-June 1977
Naphthalene	M	0.03	0.10	0.029
	95%CI	0.02-0.04	0.05-0.22	0.002-0.4
	S	2.2	2.1	8.54
	N	23	6	6
	Nu	18	6	5
	R	<0.02-0.15	0.06-0.28	<0.01-0.4
1-Methyl-naphthalene	M	0.04	0.03	
	95%CI	0.03-0.06	0.005-0.2	
	S	1.77	4.1	
	N	10	6	
	Nu	9	5	
	R	<0.01-0.1	<0.01-0.15	
2-Methyl naphthalene	M	0.02	0.04	
	95%CI	0.005-0.09	0.003-0.5	
	S	4.1	5.1	
	N	10	6	
	Nu	6	4	
	R	<0.01-0.1	<0.01-0.26	

*Pilot reverse osmosis unit.

TABLE C-3. CONCENTRATION IN µg/l OF SEA CONSTITUENTS DURING THE SECOND PERIOD

Constituent	Parameter	Plant Influent Q1	Final Effluent Q9	R.O. Influent Q22A	R.O. Effluent Q22B
		Oct.1976-Mar.1978	Oct.1976-Mar.1978	Nov.1977-Mar.1978	Nov.1977-Mar.1978
Dimethyl-phthalate	M	16	1.7		
	95%CI	11-23	0.3-8.6		
	S	1.15	1.92		
	N	3	3		
	Nu	3	3		
	R	14.7-18.7	0.9-2.8		
Diethyl-phthalate	M	<2	<2	<2	<2
	95%CI	-	-	-	-
	S	-	-	-	-
	N	11	8	6	5
	Nu	0	1	0	0
	R	<2	<2-4.5	<2	<2
Di-n-butyl-phthalate	M	<0.5	0.84	0.84	1.8
	95%CI		0.5-1.4	0.5-1.4	0.9-3.5
	S		1.54	1.68	1.69
	N		8	6	5
	Nu	3	5	6	5
	R	<0.5-0.5	<0.5-1.5	0.5-2.3	0.9-3.1
Diisobutyl-phthalate	M	2.9	0.74	0.75	1.7
	95%CI	1.4-5.9	0.1-3.8	0.2-3.3	0.7-4.0
	S	2.7	4.7	3.3	1.1
	N	11	8	6	2
	Nu	10	6	5	2
	R	<0.3-16	<0.3-4.2	<0.3-3.0	1.6-1.7
Bis-[2-ethyl-hexyl]-phthalate	M	28	3.2	7.0	6.2
	95%CI	19-42	0.6-18	5-10	1.2-32
	S	1.83	3.0	1.42	2.8
	N	11	7	6	5
	Nu	11	4	6	4
	R	15-65	<4-15	4.6-12	<4-11
PCBs as Aroclor 1242	M	3.3	<0.3	<0.3	<0.3
	95%CI	2.2-4.8	-	-	-
	S	1.77	-	-	-
	N	11	8	6	5
	Nu	11	0	0	0
	R	2-7.6	<0.3	<0.3	<0.3

(TABLE C-3 CONT.)

TABLE C-3 CONT.

Constituent	Parameter	Plant Influent Q1 Oct.1976-Mar.1978	Final Effluent Q9 Oct.1976-Mar.1978	R.O. Influent Q22A Nov.1977-Mar.1978	R.O. Effluent Q22B Nov.1977-Mar.1978
Lindane	M	0.19	<0.05	<0.05	<0.05
	95%CI	0.1-0.35	-	-	-
	S	2.1	-	-	-
	N	10	8	6	5
	Nu	8	0	0	0
	R	<0.1-0.6	<0.05	<0.05	<0.05

APPENDIX D

SECOND-PERIOD INORGANIC AND GENERAL DATA SUMMARY

TABLE D-1. CONCENTRATION IN µg/l OF HEAVY METALS DURING THE SECOND PERIOD

Metal	Parameter	Plant Influent Q1	Chem. Effluent Q2	Filt. Effluent Q6	GAC Effluent Q8	Injection Water Q10
		Oct.1976-June 1977	Oct.1976-June 1977	Oct.1976-June 1977	Oct.1976-June 1977	Oct.1976-June 1977
Ag	M	3.0	2.5	2.6	2.5	3.1
	95%CI	2.6-3.5	2.0-3.1	2.1-3.2	2.0-3.1	2.4-4.0
	S	1.48	1.74	1.66	1.66	2.46
	N	27	27	27	27	49
	Nu	27	26	25	25	47
	R	1.5-5.0	<1.0-5.0	<1.0-5.0	<1.0-5.0	<0.1-10
Ba	M	77	32	26	26	9.9
	95%CI	68-87	26-39	21-33	21-33	8.3-11.8
	S	1.35	1.64	1.78	1.78	1.86
	N	26	26	62	26	48
	Nu	26	26	26	26	48
	R	40-177	15-114	10-97	12-114	1.2-48
Cd	M	26	2.0	1.4	1.3	0.42
	95%CI	22-31	1.6-2.5	1.1-1.8	1-1.7	0.33-0.53
	S	1.60	1.97	2.04	2.05	2.35
	N	32	32	32	32	54
	Nu	32	32	32	32	54
	R	12-97	0.4-8.4	0.3-5.4	0.3-9.8	0.1-1.5
Cr	M	140	30	29	18	3.7
	95%CI	122-160	24-38	22-38	14-23	2.8-4.8
	S	1.48	2.00	2.24	2.18	2.76
	N	33	33	33	33	55
	Nu	33	33	33	33	55
	R	62-490	9-111	8-219	4-92	0.5-49

(TABLE D-1 CONT.)

TABLE D-1 CONT.

Metal	Parameter	Plant Influent Q1 Oct.1976-June 1977	Chem. Effluent Q2 Oct.1976-June 1977	Filt. Effluent Q6 Oct.1976-June 1977	GAC Effluent Q8 Oct.1976-June 1977	Injection Water Q10 Oct.1976-June 1977
Cu	M	250	68	56	20	8
	95%CI	218-287	58-80	47-67	15-26	6.4-10
	S	1.42	1.52	1.58	1.97	2.16
	N	27	27	27	27	49
	Nu	27	27	27	27	49
	R	129-466	19-122	12-114	4-63	1-50
Fe	M	280	22	105	36	45
	95%CI	231-340	15-32	69-160	26-50	37-55
	S	1.76	3.03	3.41	2.66	2.18
	N	33	33	33	33	55
	Nu	33	33	33	33	55
	R	52-780	2-216	13-1500	2-175	10-280
Hg	M	1.6	1.9	1.9	1.7	1.3
	95%CI	0.93-2.8	1.4-2.5	1.3-2.7	1.1-2.5	1.1-1.5
	S	3.83	1.99	2.36	2.60	1.77
	N	26	25	26	25	50
	Nu	26	25	26	25	50
	R	0.1-177	1-11	0.8-46	0.5-57	0.6-11
Mn	M	33	1.5	3.2	3.7	3.5
	95%CI	29-38	1.0-2.3	2.2-4.7	2.9-4.7	3-4.1
	S	1.48	3.39	3.16	2.03	1.78
	N	33	33	33	33	55
	Nu	33	33	33	33	55
	R	9-98	0.2-45	0.3-34	0.8-26	1.3-49
Pb	M	16	2.9	3.0	2.2	1.2
	95%CI	13-20	2.1-4.0	1.7-5.3	1.3-3.8	0.87-1.6
	S	1.76	2.22	4.13	3.88	3.08
	N	26	26	26	26	48
	Nu	26	26	26	26	48
	R	3.3-62	0.6-10.9	0.2-71	0.2-72	0.1-9.8
Se	M	<2.5	<2.5	<3	<4	<10
	95%CI	-	-	-	-	-
	S	-	-	-	-	-
	N	33	33	33	33	55
	Nu	0	0	0	0	0
	R	<2.5	<2.5	<3	<4	<10

(TABLE D-1 CONT.)

TABLE D-1 CONT.

Metal	Parameter	Plant Influent Q1	Chem. Effluent Q2	Filt. Effluent Q6	GAC Effluent Q8	Injection Water Q10
		Oct.1976-June 1977	Oct.1976-June 1977	Oct.1976-June 1977	Oct.1976-June 1977	Oct.1976-June 1977
Zn	M	350	135	319	81	22
	95%CI	300-408	81-226	239-426	49-134	11-44
	S	1.47	3.57	2.07	3.59	11.6
	N	27	26	27	27	48
	Nu	27	26	27	27	48
	R	130-830	5-640	70-2000	5-304	0.1-490
As	M	<5	<5	<5	<5	<10
	95%CI	-	-	-	-	-
	S	-	-	-	-	-
	N	27	27	27	27	49
	Nu	0	0	0	0	0
	R	<5	<5	<5	<5	<10

TABLE D-2. CONCENTRATION OF GENERAL PARAMETERS DURING THE SECOND PERIOD

A. Sampling Locations Q1, Q2, Q4, and Q6.

Constituent	Parameter	Plant Influent Q1	Chem. Effluent Q2	Strip. Effluent Q4	Filt. Effluent Q6
		Oct.1976-Mar.1978	Oct.1976-Mar.1978		Oct.1976-Mar.1978
COD, mg/l	M	141	52		42
	95%CI	137-144	51-53		41-43
	S	1.23	1.20		1.26
	N	274	274		272
	Nu	274	274		272
	R	89-288	34-109		7-78
TOC, mg/l	M	30.0	21.5		14.4
	95%CI	27.3-33.0	20.2-23.0		13.9-14.9
	S	1.22	1.14		1.24
	N	19	19		156
	Nu	19	19		156
	R	23-55	18-30		7.5-28
Electroconductivity, uS/cm	M	1730	1980		
	95%CI	1700-1756	1950-2010		
	S	1.15	1.16		
	N	341	344		
	Nu	341	344		
	R	1230-2730	1240-3460		
Total Coliforms, MPN/100 ml (10^6 MPN/100 ml for Q1)	M	89	0.21		5
	95%CI	41.2-192	0.03-1.3		3.1-8.0
	S	19	7.11		14.6
	N	56	35		212
	Nu	56	7		125
	R	$3.1-10^5$	<1-10		<1-3600
Fecal Coliforms, MPN/100 ml (10^6 MPN/100 ml for Q1)	M	25	<1		0.25
	95%CI	11-56	-		0.2-0.4
	S	21.4	-		6.71
	N	55	35		218
	Nu	55	1		57
	R	$1.1-10^5$	<1-1		<1-32
B, mg/l	M	0.94	0.81		
	95%CI	0.89-0.99	0.74-0.88		
	S	1.23	1.30		
	N	61	34		
	Nu	61	34		
	R	0.7-1.8	0.5-1.6		

(TABLE D-2A CONT.)

TABLE D-2A CONT.

CONSTITUENT	Parameter	Plant Influent Q1 Oct.1976-Mar.1978	Chem. Effluent Q2 Oct.1976-Mar.1978	Strip. Effluent Q4 Oct.1976-Mar.1978	Filt. Effluent Q6 Oct.1976-Mar.1978
Ca, mg/l	M	124			
	95%CI	112-137			
	S	1.53			
	N	70			
	Nu	70			
	R	59-443			
F, mg/l	M	1.4			
	95%CI	1.3-1.5			
	S	1.18			
	N	27			
	Nu	27			
	R	0.9-1.8			
Mg, mg/l	M	24	0.16		
	95%CI	23-25	0.13-0.19		
	S	1.12	1.75		
	N	61	35		
	Nu	61	35		
	R	20-33	0.08-0.5		
Org-N, mg/l	M	7.4	3.1	2.2	
	95%CI	7.2-7.6	3-3.2	2.1-2.3	
	S	1.25	1.47	1.25	
	N	273	273	111	
	Nu	273	273	111	
	R	3.1-23	0.5-14	1.5-4.3	
NH_3-N, mg/l	M	30	26	5	
	95%CI	28-32	25-27	4.6-5.4	
	S	1.68	1.54	1.80	
	N	269	266	206	
	Nu	269	266	206	
	R	12-138	4-85	1-18	
Turbidity, TU	M	42	1.2		0.4
	95%CI	41-43	1.1-1.3		0.37-0.43
	S	1.36	1.64		1.68
	N	319	325		237
	Nu	319	325		237
	R	19-95	0.1-7.2		0.1-3.9

(TABLE D-2A CONT.)

TABLE D-2A CONT.

CONSTITUENT	Parameter	Plant Influent Q1 Oct.1976-Mar.1978	Chem. Effluent Q2 Oct.1976-Mar.1978	Strip. Effluent Q4 Oct.1976-Mar.1978	Filt. Effluent Q6 Oct.1976-Mar.1978
NO_3^--N, mg/l	M	0.23			
	95%CI	0.16-0.34			
	S	2.20			
	N	23			
	Nu	19			
	R	<0.1-0.9			
TDS, mg/l	M	1010			
	95%CI	986-1030			
	S	1.11			
	N	76			
	Nu	76			
	R	830-1296			

(TABLE D-2 CONT.)

B. Sampling Locations Q8, Q9, Q10, Q22A, and Q22B

Constituent	Parameter	GAC Effluent Q8	Final Effluent Q9	Injection Water Q10	R.O. Influent Q22A	R.O. Effluent Q22B
		Oct.1976-Mar.1978	Oct.1976-Mar.1978	Oct.1976-Mar.1978	Nov.1977-Mar.1978	Nov.1977-Mar.1978
COD, mg/l	M	16.6		9.6	21.5	2.2
	95%CI	15.9-17.4		9.0-10.3	19.9-23.2	1.5-3.2
	S	1.46		1.55	1.29	2.79
	N	264		148	42	49
	Nu	264		148	42	31
	R	4-51		1-42	13-41	<1-18
TOC, mg/l	M	7.0				
	95%CI	6.6-7.4				
	S	1.41				
	N	163				
	Nu	163				
	R	2.5-15				
Electro-conductivity, µS/cm	M		1330	708		113
	95%CI		1307-1354	689-728		110-117
	S		1.12	1.31		1.16
	N		159	377		90
	Nu		159	377		90
	R		1000-1840	140-1370		76-220
Total Coliforms, MPN/100 ml	M		0.01	0.03		
	95%CI		18	0.01-0.1		
	S		33.2	18.4		
	N		115	116		
	Nu		19	20		
	R		<1-101	<1-160		
Fecal Coliforms, MPN/100 ml	M		<1	<1		
	95%CI		-	-		
	S		-	-		
	N		115	116		
	Nu		0	1		
	R		<1	<1-3		
B, mg/l	M		0.59	0.33		
	95%CI		0.53-0.66	0.3-0.36		
	S		1.30	1.43		
	N		23	56		
	Nu		23	56		
	R		0.3-0.8	0.1-0.6		

(TABLE D-2B CONT.)

TABLE D-2B CONT.

Constituent	Parameter	GAC Effluent Q8	Final Effluent Q9	Injection Water Q10	R.O. Influent Q22A	R.O. Effluent Q22B
		Oct.1976-Mar.1978	Oct.1976-Mar.1978	Oct.1976-Mar.1978		
Ca	M		148	36		
	95%CI		124-176	33-39		
	S		1.76	1.42		
	N		41	69		
	Nu		41	69		
	R		24-314	7-94		
F	M		0.6	0.6		
	95%CI		0.52-0.7	0.58-0.63		
	S		1.41	1.16		
	N		23	50		
	Nu		23	50		
	R		0.3-0.9	0.4-0.8		
Mg	M		0.35	0.50		
	95%CI		0.24-0.51	0.47-0.54		
	S		2.33	1.30		
	N		22	57		
	Nu		22	57		
	R		0.1-1.8	0.2-1.0		
Org-N	M		1.1	0.4		
	95%CI		1.1-1.2	0.36-0.44		
	S		1.45	1.80		
	N		265	150		
	Nu		265	150		
	R		0.1-3.8	0.1-3.3		
NH_3-N	M		2.0	0.6		
	95%CI		1.7-2.3	0.5-0.71		
	S		3.05	3.06		
	N		261	195		
	Nu		228	159		
	R		<0.1-14	<0.1-7.6		
Turbidity	M			0.4		
	95%CI			0.38-0.42		
	S			1.78		
	N			360		
	Nu			360		
	R			0.1-3.3		

(TABLE D-2B CONT.)

TABLE D-2B CONT.

Constituent	Parameter	GAC Effluent Q8	Final Effluent Q9	Injection Water Q10	R.O. Influent Q22A	R.O. Effluent Q22B
		Oct.1976-Mar.1978	Oct.1976-Mar.1978	Oct.1976-Mar.1978		
NO_3^--N, mg/l	M		0.40	0.38		
	95%CI		0.28-0.58	0.28-0.56		
	S		2.41	3.23		
	N		24	56		
	Nu		23	56		
	R		<0.1-1.8	<0.1-3.5		
TDS, mg/l	M		892	413		
	95%CI		816-975	390-438		
	S		1.23	1.26		
	N		23	60		
	Nu		23	60		
	R		526-1216	214-528		

APPENDIX E

THIRD-PERIOD ORGANIC DATA SUMMARY

TABLE E-1. CONCENTRATION IN µg/l OF VOA CONSTITUENTS DURING THE THIRD PERIOD

A. Sampling Locations Q1, Q2, Q4, Q6, and Q9.

Constituent	Parameter	Plant Influent Q1	Chem. Effluent Q2	Strip. Effluent Q4	Filt. Effluent Q6	Final Effluent Q9
		3/1/78-12/31/78	3/1/78-12/31/78	3/1/78-12/31/78	3/1/78-12/31/78	3/1/78-12/31/78
Chloroform	M	3.15	4.1	0.88	5.3	8.6
	95%CI	2.5-3.9	3.2-5.3	0.53-1.5	3-9.3	6.4-11
	S	2.01	1.48	2.12	3.0	2.04
	N	37	12	11	17	26
	Nu	37	12	11	17	26
	R	0.8-17	2.6-6.4	0.4-3.2	0.4-33	2.0-31
Bromodi-chloromethane	M	0.53	0.56	<0.1	1.76	2.7
	95%CI	0.46-0.62	0.46-0.68	-	0.90-3.5	1.8-4.1
	S	1.60	1.37	-	3.4	2.79
	N	37	12	11	16	25
	Nu	37	12	3	15	25
	R	0.2-3.2	0.4-1.0	<0.1-0.1	<0.1-21	0.3-17
Dibromo-chloromethane	M	0.69	0.79	0.14	0.65	1.29
	95%CI	0.59-0.81	0.67-0.93	0.10-0.19	0.34-1.21	0.86-1.9
	S	1.66	1.29	1.37	3.4	2.76
	N	38	12	11	17	26
	Nu	38	12	7	16	26
	R	0.2-1.8	0.4-1.0	<0.1-0.2	<0.1-8.2	0.1-8.2
Tribromo-methane	M	0.40	0.67	<0.1	0.41	0.28
	95%CI	0.28-0.56	0.55-0.82	-	0.22-0.75	0.27-0.54
	S	2.54	1.33	-	2.19	2.06
	N	38	12	11	17	26
	Nu	31	10	1	9	18
	R	<0.1-6.4	<0.1-1.0	<0.1-0.4	<0.1-1.3	<0.1-1.4

(TABLE E-1A CONT.)

TABLE E-1A CONT.

Constituent	Parameter	Plant Influent Q1	Chem. Effluent Q2	Strip. Effluent Q4	Filt. Effluent Q6	Final Effluent Q9
		3/1/78-12/31/78	3/1/78-12/31/78	3/1/78-12/31/78	3/1/78-12/31/78	3/1/78-12/31/78
Carbon tetrachloride	M	0.033	<0.1	<0.1	0.07	0.16
	95%CI	0.01-0.08	-	-	0.03-0.17	0.12-0.22
	S	2.31	-	-	3.34	2.05
	N	36	12	11	17	25
	Nu	6	3	4	10	24
	R	<0.1-0.2	<0.1-0.1	<0.1-0.1	<0.1-0.6	<0.1-0.5
1,1,1-Trichloroethane	M	3.25	4.7	0.43	0.16	0.20
	95%CI	2.1-5	2.4-9	0.19-0.95	0.03-0.75	0.07-0.55
	S	3.82	2.80	3.25	11.3	8.1
	N	38	12	11	17	25
	Nu	38	12	11	12	19
	R	0.3-71	0.6-10.0	0.1-4.8	0.1-30	<0.1-41
Trichloroethylene	M	0.74	0.86	<0.2	<0.1	<0.1
	95%CI	0.4-1.4	0.2-3.2	-	-	-
	S	3.8	2.9	-	-	-
	N	22	5	4	4	14
	Nu	20	5	1	0	1
	R	<0.1-20	0.3-4.1	<0.1-2	<0.1	<0.1-0.1
Tetrachloroethylene	M	1.67	2.5	0.13	0.16	0.83
	95%CI	1.3-2.2	1.6-3.9	0.06-0.29	0.09-0.28	0.56-1.2
	S	2.37	1.99	2.59	2.47	2.49
	N	38	12	11	17	25
	Nu	38	12	8	13	24
	R	0.2-9.6	0.7-9.1	<0.1-0.5	<0.1-0.6	<0.1-7.6

B. Sampling Locations Q7-05, Q7-12, Q22A, Q22B, Q21A, and Q21B

Constituent	Parameter	Column Effluent Q7-05	Column Effluent Q7-12	R.O. Influent Q22A	R.O. Effluent Q22B	R.O. Influent* Q21A	R.O. Effluent* Q21B
		7/78-1/79	7/78-1/79	3/1/78-12/31/78	3/1/78-12/31/78	8/78-1/79	8/78-1/79
Chloroform	M	7.06	5.32	7.48	0.97	5.50	5.5
	95%CI	4.4-11.4	2.8-10.2	6.2-9	0.68-1.4	3.9-7.7	4.1-7.3
	S	2.21	2.50	1.73	2.48	1.74	1.60
	N	13	10	32	30	13	13
	Nu	13	10	32	28	13	13
	R	2.1-3.2	1.0-19	3.2-31	<0.1-7	3.2-21	3.4-17
Bromodi-chloromethane	M	1.88	0.55	0.81	0.24	0.87	0.95
	95%CI	1.2-2.8	0.2-1.3	0.55-1.2	0.18-0.31	0.61-1.3	0.69-1.3
	S	1.98	3.35	2.60	1.95	1.76	1.66
	N	13	11	27	29	12	12
	Nu	13	10	25	26	12	12
	R	1.0-9.1	<01.-4.8	<0.1-2.7	<0.1-0.7	0.4-1.9	0.5-2.1
Dibromo-chloromethane	M	0.62	0.09	0.31	0.13	0.82	0.91
	95%CI	0.4-0.9	0.01-0.7	0.20-0.48	0.09-0.20	0.69-0.97	0.74-1.1
	S	1.98	6.66	2.45	2.33	1.32	1.37
	N	14	11	27	30	13	13
	Nu	14	6	19	19	13	13
	R	0.3-2.3	<0.1-1.3	<0.1-1.2	<0.1-0.6	0.6-1.7	0.6-1.9
Tribromo-methane	M	0.17	0.02	0.076	0.007	0.63	0.65
	95%CI	0.03-0.9	10^{-6}-93	0.03-0.22	0.0005-0.10	0.47-0.84	0.44-1.0
	S	3.69	30	5.99	12.4	1.49	1.73
	N	14	11	27	30	13	13
	Nu	5	3	13	6	10	10
	R	<0.1-1.7	<0.1-3.4	<0.1-1.2	<0.1-0.9	<0.1-1.0	<0.1-1.5
Carbon tetrachloride	M	0.05	0.06	0.056	0.008	<0.1	<0.1
	95%CI	0.01-0.2	0.02-0.2	0.03-0.10	0.001-0.06	-	-
	S	3.23	2.22	1.96	12.3	-	-
	N	14	11	21	30	13	13
	Nu	6	4	7	8	4	5
	R	<0.1-0.4	<0.1-0.2	<0.1-0.2	<0.1-1.3	<0.1-0.1	<0.1-0.1
1,1,1-Tri-chloroethane	M	0.26	0.23	0.18	0.083	4.94	6.32
	95%CI	0.07-1.0	0.08-0.7	0.08-0.38	0.01-0.49	2.9-8.2	3.9-10
	S	9.06	2.9	6.7	21.6	2.36	2.24
	N	14	11	32	30	13	13
	Nu	13	6	27	14	13	13
	R	<0.1-13	<0.1-1.4	<0.1-45	<0.1-35	0.3-16	0.4-17

(TABLE E-1B CONT.)

TABLE E-1B CONT.

Constituent	Parameter	Column Effluent Q7-05	Column Effluent Q7-12	R.O. Influent Q22A	R.O. Effluent Q22B	R.O. Influent* Q21A	R.O. Effluent* Q21B
		7/78-1/79	7/78-1/79	3/1/78-12/31/78	3/1/78-12/31/78	8/78-1/79	8/78-1/79
Trichloroethylene	M	<0.1	<0.1	<0.1	<0.1	1.26	1.33
	95%CI	-	-	-	-	0.3-5.5	0.4-4.6
	S	-	-	-	-	2.46	1.89
	N	4	3	19	24	4	4
	Nu	1	0	0	0	4	4
	R	<0.1-2	<0.1	<0.1	<0.1	0.6-4.0	0.7-2.7
Tetrachloroethylene	M	0.19	0.23	0.17	0.20	1.49	1.80
	95%CI	0.06-0.6	0.05-1.1	0.07-0.42	0.12-0.35	1.1-1.9	1.3-2.5
	S	4.32	7.81	5.73	2.60	1.55	1.70
	N	14	11	27	30	13	13
	Nu	9	9	17	14	13	13
	R	<0.1-3.7	<0.1-24	<0.1-3.2	<0.1-0.9	0.8-3.0	0.7-4.6

*Pilot Scale.

TABLE E-2. CONCENTRATION IN µg/1 OF CLSA CONSTITUENTS DURING THE THIRD PERIOD

A. Sampling Locations Q1, Q2, Q4, Q6, and Q9

Constituent	Parameter	Plant Influent Q1	Chem. Effluent Q2	Strip. Effluent Q4	Filt. Effluent Q6	Final Effluent Q9
		3/1/78-12/31/78	8/1/78-12/31/78	8/1/78-12/31/78	7/1/78-12/31/78	3/1/78-12/31/78
Chlorobenzene	M	0.14	0.15	0.11	0.11	0.049
	95%CI	0.11-0.18	0.09-0.25	0.06-0.19	0.08-0.16	0.03-0.08
	S	2.44	1.95	1.95	1.93	3.01
	N	40	10	9	16	29
	Nu	40	9	8	15	21
	R	0.02-1.1	<0.02-0.49	<0.02-0.26	<0.02-0.25	<0.02-0.5
1,2-Di-chlorobenzene	M	0.64	0.56	0.066	0.023	0.020
	95%CI	0.47-0.88	0.33-0.95	0.02-0.23	0.01-0.05	0.007-0.06
	S	2.73	2.21	4.37	3.37	2.40
	N	40	11	10	16	29
	Nu	39	11	8	10	5
	R	<0.02-13	0.1-1.2	<0.02-0.48	<0.02-0.15	<0.02-0.11
1,3-Di-chlorobenzene	M	0.16	0.10	0.017	0.014	<0.02
	95%CI	0.12-0.21	0.07-0.13	0.0002-1.9	10^{-4}-2.8	-
	S	2.20	1.52	1.69	1.80	-
	N	39	11	10	16	29
	Nu	36	10	2	2	1
	R	<0.02-5.4	<0.02-0.18	<0.02-0.04	<0.02-0.04	<0.02-0.04
1,4-Di-chlorobenzene	M	1.85	1.29	0.103	0.066	0.012
	95%CI	1.6-2.1	1.1-1.5	0.07-0.14	0.05-0.09	0.004-0.04
	S	1.60	1.22	1.60	1.78	5.09
	N	39	11	10	16	29
	Nu	39	11	10	13	10
	R	0.7-15	0.97-1.8	0.05-0.18	0.02-0.13	<0.02-0.21
1,2,4-Tri-chlorobenzene	M	0.11	0.035	0.021	<0.02	0.000
	95%CI	0.07-0.18	0.009-0.13	10^{-5}-45	-	-
	S	3.82	3.57	2.35	-	193
	N	40	11	10	16	27
	Nu	29	6	2	1	2
	R	<0.02-3.1	<0.02-0.33	<0.02-0.08	<0.02-0.15	<0.02-0.2
Heptaldehyde	M	0.10	0.12	<0.02	0.28	0.029
	95%CI	0.06-0.18	0.08-0.19	-	0.21-0.38	0.008-0.11
	S	2.78	1.53	-	1.56	5.39
	N	25	10	9	15	24
	Nu	15	6	1	11	9
	R	<0.06-0.55	<0.06-0.20	<0.02-0.09	<0.06-0.46	<0.06-0.59

(TABLE E-2 A CONT.)

TABLE E-2A CONT.

Constituent	Parameter	Plant Influent Q1	Chem. Effluent Q2	Strip. Effluent Q4	Filt. Effluent Q6	Final Effluent Q9
		3/1/78-12/31/78	8/1/78-12/31/78	8/1/78-12/31/78	7/1/78-12/31/78	3/1/78-12/31/78
Heptyl-cyanide	M	0.002	0.047	0.048	0.028	0.003
	95%CI	10^{-4}-0.04	0.02-0.11	0.02-0.13	0.01-0.08	10^{-5}-0.78
	S	11.0	1.39	2.17	2.62	9.41
	N	27	11	10	16	25
	Nu	5	3	5	6	3
	R	<0.02-0.31	<0.02-0.08	<0.02-0.13	<0.02-0.14	<0.02-0.28
Ethylbenzene	M	0.043	0.067	0.041	0.023	0.014
	95%CI	0.03-0.06	0.04-0.12	0.02-0.1	0.01-0.04	0.008-0.02
	S	3.07	2.38	2.36	2.42	2.22
	N	38	10	9	16	29
	Nu	32	10	6	10	12
	R	<0.02-0.5	0.3-0.42	<0.02-0.15	<0.02-0.12	<0.02-0.06
m-Xylene	M	0.035	0.086	0.070	0.046	0.020
	95%CI	0.03-0.05	0.05-0.15	0.03-0.15	0.03-0.07	0.01-0.04
	S	2.33	2.09	2.40	2.24	2.90
	N	37	10	9	16	29
	Nu	27	10	8	15	14
	R	<0.02-0.2	0.04-0.48	<0.02-0.2	<0.02-0.21	<0.02-0.1
p-Xylene	M	0.015	0.023	0.031	0.012	0.012
	95%CI	0.01-0.02	0.01-0.04	0.02-0.06	0.004-0.03	0.007-0.02
	S	1.94	2.18	1.72	2.63	1.85
	N	37	10	9	16	29
	Nu	13	8	5	6	8
	R	<0.02-0.06	<0.02-0.1	<0.02-0.07	<0.02-0.06	<0.02-0.04
Naphthalene	M	0.033	0.041	0.037	0.046	0.010
	95%CI	0.02-0.06	0.004-0.44	0.006-0.24	0.03-0.07	0.007-0.02
	S	3.74	4.43	5.83	1.67	2.74
	N	40	11	10	16	29
	Nu	21	4	6	9	4
	R	<0.02-0.54	<0.02-0.43	<0.02-0.93	<0.02-0.10	<0.02-0.08
1-Methyl-naphthalene	M	0.008	0.019	0.011	0.009	<0.02
	95%CI	0.004-0.017	0.008-0.05	0.002-0.07	0.001-0.08	-
	S	2.54	1.73	3.25	2.35	-
	N	40	11	10	16	28
	Nu	8	4	4	3	2
	R	<0.02-0.06	<0.02-0.04	<0.02-0.07	<0.02-0.04	<0.02-0.02

(TABLE E-2A CONT.)

TABLE E-2A CONT.

Constituent	Parameter	Plant Influent Q1	Chem. Effluent Q2	Strip. Effluent Q4	Filt. Effluent Q6	Final Effluent Q9
		3/1/78-12/31/78	8/1/78-12/31/78	8/1/78-12/31/78	7/1/78-12/31/78	3/1/78-12/31/78
2-Methyl naphthalene	M	0.010	0.009	0.009	0.017	<0.02
	95%CI	0.004-0.02	10^{-5}-8	10^{-3}-0.09	0.008-0.04	-
	S	4.04	2.13	2.57	1.37	-
	N	40	11	10	16	28
	Nu	15	2	3	3	0
	R	<0.02-0.18	<0.02-0.03	<0.02-0.04	<0.02-0.03	<0.02
Styrene	M	0.048	0.076	0.037	0.030	0.003
	95%CI	0.03-0.09	0.03-0.17	0.004-0.37	0.01-0.07	10^{-4}-0.05
	S	2.73	2.35	4.24	2.61	9.04
	N	24	11	9	14	23
	Nu	12	7	4	7	5
	R	<0.02-0.2	<0.02-0.25	<0.02-0.25	<0.02-0.13	<0.02-0.16

B. Sampling Locations Q7-05, Q7-12, Q22A, Q22B, Q21A, and Q21B

Constituent	Parameter	Column Effluent Q7-05	Column Effluent Q7-12	R.O. Influent Q22A	R.O. Effluent Q22B	R.O. Influent* Q21A	R.O. Effluent* Q21B
		7/78-1/79	7/78-1/79	3/78-9/78	3/78-9/78	8/78-1/79	8/78-1/79
Chlorobenzene	M	0.070	0.043	0.041	0.034	0.14	0.072
	95%CI	0.05-0.1	0.02-0.11	0.02-0.07	0.02-0.07	0.08-0.23	0.03-0.15
	S	1.85	3.39	2.24	3.0	2.12	2.98
	N	15	11	12	16	12	12
	Nu	14	9	10	12	11	11
	R	<0.02-0.15	<0.02-0.34	<0.02-0.12	<0.02-0.25	<0.02-0.32	<0.02-0.21
1,2-Di-chlorobenzene	M	0.028	<0.02	0.002	0.001	0.46	0.38
	95%CI	0.002-0.32	-	10^{-11}-10^{5}	10^{-14}-10^{7}	0.25-0.84	0.23-0.64
	S	2.68	-	8.1	13	2.32	2.15
	N	14	11	12	16	12	12
	Nu	3	1	2	2	10	11
	R	<0.02-0.15	<0.02-0.03	<0.02-0.06	<0.02-0.07	<0.02-1.2	<0.02-0.87
1,3-Di-chlorobenzene	M	<0.02	<0.02	<0.02	0.004	0.12	0.065
	95%CI	-	-	-	10^{-4}-0.1	0.08-0.17	0.04-0.1
	S	-	-	-	4.1	1.66	1.83
	N	14	11	12	16	12	12
	Nu	0	0	2	3	10	11
	R	<0.02	<0.02	<0.02-0.02	<0.02-0.05	<0.02-0.24	<0.02-0.13
1,4-Di-chlorobenzene	M	<0.02	0.006	0.001	0.015	1.19	0.99
	95%CI	-	10^{-4}-0.1	10^{-13}-10^{6}	0.006-0.04	0.94-1.5	0.83-1.2
	S	-	3.60	10.9	2.8	1.41	1.32
	N	15	11	12	16	12	12
	Nu	1	3	2	7	11	12
	R		<0.02-0.05	<0.02-0.07	<0.02-0.07	<0.02-1.8	0.51-1.4
1,2,4-Tri-chlorobenzene	M	0.000	0.003	0.017	<0.02	0.044	0.11
	95%CI	0.000	10^{-9}-10^{4}	0.003-0.09	-	0.02-0.11	0.06-0.2
	S	47	5.53	1.92	-	2.39	2.04
	N	14	11	12	16	12	12
	Nu	2	2	3	1	6	8
	R	<0.02-0.14	<0.02-0.05	<0.02-0.05	<0.02-0.03	<0.02-0.18	<0.02-0.30
Heptaldehyde	M	0.034	0.009			0.18	0.053
	95%CI	0.004-0.31	10^{-9}-10^{4}			0.13-0.25	0.02-0.12
	S	5.93	5.12			1.48	1.97
	N	14	11			12	12
	Nu	5	2			8	5
	R	<0.06-0.71	<0.06-0.12			<0.02-0.3	<0.02-0.13

(TABLE E-2B CONT.)

TABLE E-2B CONT.

Constituent	Parameter	Column Effluent Q7-05	Column Effluent Q-7-12	R.O. Influent Q22A	R.O. Effluent Q22B	R.O. Influent* Q21A	R.O. Effluent* Q21B
		7/78-1/79	7/78-1/79	3/78-9/78	3/78-9/78	8/78-1/79	8/78-1/79
Heptyl cyanide	M					0.045	0.023
	95%CI					0.02-0.08	0.004-0.13
	S					1.76	2.91
	N					12	12
	Nu					6	4
	R					<0.02-0.10	<0.02-0.11
Ethylbenzene	M	0.015	0.024	0.019	0.019	0.052	0.029
	95%CI	0.007-0.03	0.009-0.06	0.01-0.03	0.01-0.04	0.02-0.11	0.01-0.07
	S	1.85	2.84	1.81	2.1	2.69	3.31
	N	14	10	11	15	12	12
	Nu	5	7	7	7	9	9
	R	<0.02-0.04	<0.02-0.18	<0.02-0.05	<0.02-0.06	<0.02-0.46	<0.02-0.33
m-Xylene	M	0.018	0.037	0.023	0.024	0.082	0.045
	95%CI	0.009-0.03	0.01-0.11	0.01-0.04	0.01-0.04	0.04-0.16	0.02-0.12
	S	2.16	3.63	1.97	2.4	2.64	4.10
	N	14	10	12	16	12	12
	Nu	8	8	10	13	11	10
	R	<0.02-0.06	<0.02-0.39	<0.02-0.10	<0.02-0.05	<0.02-0.17	<0.02-0.65
p-Xylene	M	<0.02	0.01	<0.02	0.014	0.024	0.022
	95%CI	-	0.001-0.09	-	0.005-0.03	0.01-0.06	0.01-0.07
	S	-	4.10	-	1.90	2.74	3.44
	N	14	10	12	16	12	12
	Nu	3	4	1	4	7	7
	R	<0.02	<0.02-0.10	<0.02-0.03	<0.02-0.04	<0.02-0.12	<0.02-0.22
Naphthalene	M	0.004	0.002	0.023	0.028	0.051	0.067
	95%CI	10^{-4}-0.2	10^{-11}-10^{5}	0.01-0.05	0.01-0.06	0.01-0.22	0.01-0.38
	S	4.87	7.77	2.33	3.1	4.11	6.54
	N	15	11	12	16	12	11
	Nu	3	2	7	10	6	7
	R	<0.02-0.07	<0.02-0.06	<0.02-0.09	<0.02-0.15	<0.02-0.39	<0.02-1.4
1-Methyl naphthalene	M	<0.02	<0.02	0.009	0.001	0.018	0.017
	95%CI	-	-	0.001-0.1	10^{-5}-0.1	0.005-0.06	0.006-0.05
	S	-	-	2.9	18	1.64	2.63
	N	15	11	12	16	12	12
	Nu	1	1	3	4	3	6
	R	<0.02-0.03	<0.02-0.02	<0.02-0.05	<0.02-0.19	<0.02-0.04	<0.02-0.08

(TABLE E-2B CONT.)

TABLE E-2B CONT.

Constituent	Parameter	Column Effluent Q7-05	Column Effluent Q7-12	R.O. Influent Q22A	R.O. Effluent Q22B	R.O. Influent* Q21A	R.O. Effluent* Q21B
		7/78-1/79	7/78-1/79	3/78-9/78	3/78-9/78	8/78-1/79	8/78-1/79
2-Methyl naphthalene	M	<0.02	<0.02	0.020	0.008	0.016	0.019
	95%CI	-	-	0.007-0.06	0.002-0.03	10^{-4}-2.2	0.009-0.04
	S	-	-	1.51	2.4	1.73	1.96
	N	15	11	12	16	12	12
	Nu	0	0	3	4	2	6
	R	<0.02	<0.02	<0.02-0.04	<0.02-0.04	<0.02-0.04	<0.02-0.05
Styrene	M	0.014	0.006			0.018	0.010
	95%CI	0.006-0.03	10^{-7}-10^{3}			0.004-0.09	0.001-0.09
	S	1.93	3.53			4.62	3.94
	N	13	10			12	10
	Nu	5	2			6	4
	R	<0.02-0.04	<0.02-0.04			<0.02-0.21	<0.02-0.08

*Pilot Scale.

TABLE E-3. CONCENTRATION IN µg/l OF SEA CONSTITUENTS DURING THE THIRD PERIOD

A. Sampling Locations Q1, Q2, Q4, Q6, and Q9

Constituent	Parameter	Plant Influent Q1	Chem. Effluent Q2	Strip. Effluent Q4	Filt. Effluent Q6	Final Effluent Q9
		3/1/78-12/31/78	8/1/78-12/31/78	8/1/78-12/31/78	8/1/78-12/31/78	3/1/78-12/31/78
Dimethyl-phthalate	M	4.8	3.1	2.8	1.32	0.47
	95%CI	3.8-6.1	1.9-5.0	1.6-5.0	0.88-2.0	0.23-0.95
	S	1.98	2.05	2.15	2.13	3.18
	N	32	11	9	16	20
	Nu	32	11	9	16	13
	R	0.8-14	0.9-5.6	1.0-7.1	0.5-6.7	<0.3-6.2
Diethyl-phthalate	M	0.097	<0.3	0.21	0.62	<0.3
	95%CI	0.02-0.62	-	0.03-1.5	0.32-1.2	-
	S	9.23	-	4.79	2.56	-
	N	33	11	10	16	22
	Nu	8	1	5	10	1
	R	<0.3-12	<0.3-0.6	<0.3-2.4	<0.3-2.4	<0.3-0.3
Di-n-butyl-phthalate	M	0.79	0.23	0.88	0.59	0.33
	95%CI	0.54-1.2	0.02-2.6	0.25-3.1	0.18-1.9	0.15-0.74
	S	2.34	6.93	2.72	3.04	2.84
	N	32	11	10	14	22
	Nu	22	5	5	6	9
	R	<0.5-3.4	<0.5-6.1	<0.5-3.7	<0.5-3.7	<0.5-2.4
Dissobutyl-phthalate	M	4.7	3.2	2.3	2.0	0.27
	95%CI	3.9-5.7	2.6-3.9	1.7-3.2	1.5-2.6	0.09-0.82
	S	1.72	1.36	1.56	1.66	5.22
	N	33	11	10	16	20
	Nu	32	11	10	16	11
	R	<0.3-18	1.6-4.8	1.0-4.4	0.5-4.4	<0.3-5.7
Bis-[2-ethyl-hexyl]-phthalate	M	11	3.8	<4	3.4	3.1
	95%CI	8.6-14	1.7-8.7	-	1.7-6.7	2.2-4.4
	S	2.01	2.20	-	1.72	1.32
	N	33	11	9	16	22
	Nu	32	6	0	5	5
	R	<4-63	<4-16	<4	<4-8.3	<4-5.4
PCBs as Aroclor 1242	M	0.47	0.37	0.36	0.06	<0.3
	95%CI	0.38-0.57	0.25-0.55	0.02-6.9	0.002-2.1	-
	S	1.71	1.60	1.39	9.39	-
	N	33	11	10	15	22
	Nu	30	8	2	4	0
	R	<0.3-1.3	<0.3-0.7	<0.3-0.6	<0.3-3.0	<0.3

(TABLE E-3A CONT.)

TABLE E-3A CONT.

Constituent	Parameter	Plant Influent Q1	Chem. Effluent Q2	Strip. Effluent Q4	Filt. Effluent Q6	Final Effluent Q9
		3/1/78-12/31/78	8/1/78-12/31/78	8/1/78-12/31/78	8/1/78-12/31/78	3/1/78-12/31/78
Lindane	M	0.14	<0.05	0.023	0.088	<0.05
	95%CI	0.13-0.15	-	10^{-3}-0.75	0.06-0.12	-
	S	1.24	-	4.08	1.80	-
	N	33	11	9	16	22
	Nu	33	2	3	16	0
	R	0.09-0.19	<0.05-0.06	<0.05-0.21	0.04-0.7	<0.05

B. Sampling Locations Q7-05, Q7-12, Q22A, Q22B, Q21A, and Q21B

Constituent	Parameter	Column Effluent Q7-05	Column Effluent Q7-12	R.O. Influent Q22A	R.O. Effluent Q22B	R.O. Influent* Q21A	R.O. Effluent* Q21B
		7/78-1/79	7/78-1/79	3/78-9/78	3/78-9/78	8/78-1/79	8/78-1/79
Dimethyl-phthalate	M	1.72	0.47	2.4	1.0	1.30	1.05
	95%CI	1.1-2.7	0.22-1.0	1.1-5.2	0.6-1.7	0.92-1.8	0.6-1.8
	S	1.83	2.43	2.3	2.3	1.72	2.16
	N	12	13	7	12	12	11
	Nu	9	8	7	12	12	10
	R	<0.3-3.8	<0.3-1.8	<0.3-10	0.3-5.3	0.6-4.1	<0.3-5.1
Diethyl-phthalate	M	0.27	0.21	0.12	<0.3	0.45	0.52
	95%CI	0.08-0.9	10^{-5}-10^{3}	10^{-10}-10^{7}	-	0.22-0.92	0.28-0.96
	S	2.62	2.85	8	-	2.17	2.21
	N	15	13	7	12	11	12
	Nu	5	2	2	0	7	9
	R	<0.3-1.2	<0.3-1.2	<0.3-2.1	<0.3	<0.3-1.6	<0.3-1.7
Di-n-butyl-phthalate	M	0.49	0.50	0.90	1.1	0.69	0.73
	95%CI	0.18-1.3	0.11-2.2	0.2-4	0.7-1.7	0.27-1.8	0.41-1.3
	S	2.25	3.29	3.5	1.9	3.44	2.27
	N	14	13	7	12	11	12
	Nu	5	5	5	10	9	10
	R	<0.5-2.2	<0.5-3.7	<0.5-4.9	<0.5-3.4	<0.5-4.5	<0.5-2.8
Dissobutyl-phthalate	M	0.26	0.35	0.33	0.23	2.86	2.47
	95%CI	0.11-0.63	10^{-4}-10^{3}	0.07-1.7	0.02-2.3	2.3-3.5	1.8-3.4
	S	2.32	2.49	1.92	9.1	1.38	1.57
	N	15	13	7	12	12	11
	Nu	6	2	3	6	12	11
	R	<0.3-1.0	<0.3-1.6	<0.3-0.83	<0.3-6.9	1.5-4.4	1.5-4.6
Bis-[2-ethyl-hexyl]-phthalate	M	4.8	3.3	7.8	2.9	<4	1.0
	95%CI	3.8-6.1	1.3-8.3	1.4-42	0.8-10	-	0.05-22
	S	1.21	2.40	3.9	2.8	-	6.89
	N	15	13	7	11	12	12
	Nu	5	6	5	5	0	4
	R	<4-6.4	<4-14	<4-63	<4-16	<4	<4-29
PCBs as Aroclor 1242	M	<0.3	<0.3	<0.3	<0.3	0.35	<0.3
	95%CI	-	-	-	-	0.25-0.49	-
	S	-	-	-	-	1.48	-
	N	15	13	7	12	12	12
	Nu	0	0	0	2	8	3
	R	<0.3	<0.3	<0.3	<0.3-0.3	<0.3-0.60	<0.3-0.3

(TABLE E-3B CONT.)

TABLE E-3B CONT.

Constituent	Parameter	Column Effluent Q7-05	Column Effluent Q7-12	R.O. Influent Q22A	R.O. Effluent Q22B	R.O. Influent* Q21A	R.O. Effluent* Q21B
		7/78-1/79	7/78-1/79	3/78-9/78	3/78-9/78	8/78-1/79	8/78-1/79
Lindane	M	<0.05	<0.05	<0.05	<0.05	0.081	0.059
	95%CI	-	-	-	-	0.06-0.1	0.05-0.07
	S	-	-	-	-	1.39	1.27
	N	15	13	7	12	12	12
	Nu	0	0	0	0	8	7
	R	<0.05	<0.05	<0.05	<0.05	<0.05-0.12	<0.05-0.08

*Pilot Scale.

APPENDIX F

THIRD-PERIOD INORGANIC AND GENERAL DATA SUMMARY

TABLE F-1. CONCENTRATION IN µg/l OF HEAVY METALS DURING THE THIRD PERIOD

Metal	Parameter	Plant Influent Q1	Chem. Effluent Q2	Filt. Effluent Q6	GAC Effluent Q8	Injection Water Q10
		3/1/78-12/31/78	3/1/78-12/31/78	3/1/78-12/31/78	3/1/78-12/31/78	3/1/78-12/31/78
Ag	M	1.19	0.46	0.77	0.69	0.91
	95%CI	0.6-2.2	0.1-1.8	0.2-3.2	0.3-1.4	0.7-1.2
	S	2.22	6.04	3.91	1.57	2.48
	N	9	9	6	4	40
	Nu	9	9	6	4	40
	R	0.4-3.5	0.1-7.3	0.1-3.3	0.6-1.1	0.1-3.8
Ba	M	30	9.2	7.8	7.4	3.2
	95%CI	23.3-38.7	6.1-14.0	4.8-12.6	2.2-25.2	2.3-4.4
	S	1.39	1.72	1.58	2.16	2.78
	N	9	9	6	4	39
	Nu	9	9	6	4	39
	R	15-42	3.6-21	4.5-15	3.1-15	0.1-1.1
Cd	M	33	8.7	7.2	9.5	1.1
	95%CI	18.7-58	5.2-14.7	3.0-17.7	6.3-14.4	0.7-1.9
	S	2.09	1.97	2.36	1.30	5.43
	N	9	9	6	4	40
	Nu	9	9	6	4	40
	R	3.5-54	2-19	1.4-15	7.2-12	0.1-16
Cr	M	48	6.6	5.6	3.1	1.6
	95%CI	35.5-65.0	4.3-10.2	3.0-10.4	2.0-4.7	1.1-2.4
	S	1.48	1.76	1.81	1.30	2.80
	N	9	9	6	4	40
	Nu	9	9	6	4	38
	R	21-74	3.4-14	2-10	2.1-3.7	<1-17

(TABLE F-1 CONT.)

TABLE F-1 CONT.

Metal	Parameter	Plant Influent Q1	Chem. Effluent Q2	Filt. Effluent Q6	GAC Effluent Q8	Injection Water Q10
		3/1/78-12/31/78	3/1/78-12/31/78	3/1/78-12/31/78	3/1/78-12/31/78	3/1/78-12/31/78
Cu	M	72	23	36	16	12
	95%CI	37.4-139	10.6-49.7	15.8-81.9	2.8-90	8.7-16.5
	S	2.34	2.72	2.19	2.96	2.67
	N	9	9	6	4	36
	Nu	9	9	6	4	36
	R	11-160	2-51	6-65	4-41	1-330
Fe	M	98	13	28	42	26
	95%CI	73.6-130	7.4-22.8	5.6-140	31.0-56.9	19.9-33.9
	S	1.45	2.08	4.63	1.21	2.33
	N	9	9	6	4	39
	Nu	9	9	6	4	39
	R	58-210	3-49	5-210	34-50	1-170
Hg	M	<1	<1	<1	<1	<1
	95%CI	-	-	-	-	-
	S	-	-	-	-	-
	N	4	6	5	4	37
	Nu	0	0	0	0	5
	R	<1	<1	<1	<1	<1-2
Mn	M	29	2.6	1.27	1.71	2.53
	95%CI	24.4-34.4	0.6-11.3	0.7-2.3	0.5-5.7	1.8-3.5
	S	1.25	6.76	1.78	2.14	2.83
	N	9	9	6	4	39
	Nu	9	9	6	4	39
	R	22-41	0.1-1.5	0.7-3.1	1.1-5.4	0.4-62
Pb	M	7.1	3.1	3.1	1.0	1.55
	95%CI	5.1-9.8	1.6-6.1	1.2-8.0	10^{-7}-10^{7}	1.0-2.4
	S	1.52	2.09	2.15	6.35	2.82
	N	9	9	6	4	40
	Nu	9	7	5	2	26
	R	3.6-11	<1-6.8	<1-7.2	<1-7.2	<1-20
Se	M	<5	<5	<5	<5	<5
	95%CI	-	-	-	-	-
	S	-	-	-	-	-
	N	6	6	6	4	34
	Nu	0	0	0	0	0
	R	<5	<5	<5	<5	<5

(TABLE F-1 CONT.)

TABLE F-1 CONT.

Metal	Parameter	Plant Influent Q1	Chem. Effluent Q2	Filt. Effluent Q6	GAC Effluent Q8	Injection Water Q10
		3/1/78-12/31/78	3/1/78-12/31/78	3/1/78-12/31/78	3/1/78-12/31/78	3/1/78-12/31/78
Zn	M	127	<100	222	<100	72
	95%CI	81-198	-	112-439	-	31-169
	S	1.43	-	1.73	-	1.41
	N	6	6	6	4	38
	Nu	5	0	5	0	3
	R	<100-200	<100	<100-440	<100	<100-150
As	M	<5	<5	<5	<5	<5
	95%CI	-	-	-	-	-
	S	-	-	-	-	-
	N	6	6	6	4	32
	Nu	0	0	0	0	0
	R	<5	<5	<5	<5	<5

TABLE F-2. CONCENTRATION OF GENERAL PARAMETERS DURING THE THIRD PERIOD

A. Sampling Locations Q1, Q2, Q6, and Q8

Constituent	Parameter	Plant Influent Q1	Chem. Effluent Q2	Filt. Effluent Q6	GAC Effluent Q8
		3/1/78-12/31/78	3/1/78-12/31/78	3/1/78-12/31/78	3/1/78-12/31/78
COD, mg/l	M	47	27	24	12.3
	95%CI	46-48	26.5-27.5	23.5-24.5	11.7-13.0
	S	1.21	1.12	1.14	1.36
	N	155	156	155	125
	Nu	155	156	155	125
	R	21-86	20-38	17-35	3.9-26
TOC, mg/l	M	12.4	10		6.2
	95%CI	11-13	9.5-10.5		5.8-6.7
	S	1.41	1.17		1.43
	N	45	44		91
	Nu	45	44		91
	R	1.0-24	7-13		1.5-19
Electroconductivity, µS/cm	M	1500*	1560		
	95%CI	1493-1506	1525-1596		
	S	1.12	1.20		
	N	269	246		
	Nu	269	246		
	R	1200-2800	1180-2400		
Total Coliforms, MPN/100 ml (10^6 MPN/100 ml for Q1)	M	1.64	0.2	0.10	
	95%CI	0.86-3.1	0.03-1.3	0.03-0.4	
	S	6.6	23	116	
	N	33	24	144	
	Nu	33	13	48	
	R	1-55	<1-510	<1-6300	
Fecal Coliforms, MPN/100 ml (10^6 MPN/100 ml for Q1)	M	0.55	0.08	0.001	
	95%CI	0.13-2.4	0.002-2	10^{-4}-0.01	
	S	68	40	114	
	N	33	24	151	
	Nu	32	7	16	
	R	<1-70,000	<1-59	<1-220	
B, mg/l	M	0.74			
	95%CI	0.69-0.80			
	S	1.27			
	N	40			
	Nu	40			
	R	0.5-1.6			

*Distribution falls outside 10% K-S limits.

(TABLE F-2A CONT.)

TABLE F-2A. CONT.

Constituent	Parameter	Plant Influent Q1	Chem. Effluent Q2	Strip. Effluent Q4	Filt. Effluent Q6
		3/1/78-12/31/78	3/1/78-12/31/78	3/1/78-12/31/78	3/1/78-12/31/78
Ca, mg/l	M				
	95%CI				
	S				
	N				
	Nu				
	R				
F, mg/l	M	1.28			
	95%CI	1.2-1.35			
	S	1.20			
	N	40			
	Nu	40			
	R	0.7-2.8			
Mg, mg/l	M				
	95%CI				
	S				
	N				
	Nu				
	R				
Org-N, mg/l	M	2.0	1.0	1.0	
	95%CI	1.9-2.1	0.94-1.1	0.97-1.0	
	S	1.33	1.43	1.27	
	N	117	117	43	
	Nu	117	117	43	
	R	1-4.8	0.2-3.1	0.6-2.0	
NH_3-N, mg/l	M	4.0	5.9	4.4	
	95%CI	3.4-4.7	5.3-6.6	4.0-4.9	
	S	2.87	2.03	1.68	
	N	164	164	90	
	Nu	162	164	90	
	R	<0.1-48	0.6-47	1.1-12	
Turbidity, TU	M	6.5	0.54		0.36
	95%CI	5.8-7.3	0.5-0.58		0.34-0.38
	S	2.80	1.77		1.47
	N	275	276		275
	Nu	275	276		275
	R	0.17-64	0.08-3.1		0.09-1.0

(TABLE F-2A CONT.)

TABLE F-2A. CONT.

Constituent	Parameter	Plant Influent Q1	Chem. Effluent Q2	Strip. Effluent Q4	Filt. Effluent Q6
		3/1/78-12/31/78	3/1/78-12/31/78	3/1/78-12/31/78	3/1/78-12/31/78
NO_3^--N, mg/l	M	2.78			
	95%CI	2.03-3.81			
	S	4.04			
	N	79			
	Nu	75			
	R	<0.1-18			
Na, mg/l	M	171			
	95%CI	164-178			
	S	1.12			
	N	31			
	Nu	31			
	R	140-220			
Cl, mg/l	M	192			
	95%CI	187-197			
	S	1.08			
	N	31			
	Nu	31			
	R	165-230			
SO_4, mg/l	M	205			
	95%CI	186-225			
	S	1.29			
	N	30			
	Nu	30			
	R	130-340			
Total Hardness, mg/l as $CaCO_3$	M	296			
	95%CI	282-311			
	S	1.14			
	N	31			
	Nu	31			
	R	232-400			
TDS, mg/l	M	902			
	95%CI	868-937			
	S	1.11			
	N	31			
	Nu	31			
	R	758-1160			

(TABLE F-2A CONT.)

TABLE F-2A. CONT.

Constituent	Parameter	Plant Influent Q1 3/1/78-12/31/78	Chem. Effluent Q2 3/1/78-12/31/78	Strip. Effluent Q4 3/1/78-12/31/78	Filt. Effluent Q6 3/1/78-12/31/78
MBAS, mg/l	M	0.25			
	95%CI	0.22-0.29			
	S	1.44			
	N	28			
	Nu	28			
	R	0.13-0.76			
Phenol, µg/l	M	4.9			
	95%CI	4.2-5.7			
	S	1.51			
	N	30			
	Nu	29			
	R	<1.0-11.4			
Cyanide, µg/l	M	25			
	95%CI	20-31			
	S	1.81			
	N	32			
	Nu	32			
	R	10-110			
Color, units	M	37			
	95%CI	35-39			
	S	1.14			
	N	30			
	Nu	30			
	R	30-55			

(TABLE F-2 CONT.)

B. Sampling Locations Q9, Q10, Q22A, and Q22B

Constituent	Parameter	Final Effluent Q9	Injection Water Q10	R.O. Influent Q22A	R.O. Effluent Q22B
		3/1/78-12/31/78	3/1/78-12/31/78	3/1/78-12/31/78	3/1/78-12/31/78
COD, mg/l	M		6.0	14.6	1.34
	95%CI		5.6-6.5	14.1-15.1	1.13-1.58
	S		1.63	1.23	2.17
	N		156	154	154
	Nu		153	154	83
	R		<1-23	8.8-30	<1-8
TOC, mg/l	M			7.2	2.6
	95%CI			6.2-8.3	2.2-3.1
	S			1.36	1.47
	N			20	20
	Nu			20	20
	R			4-15	1-5
Electroconductivity, µS/cm	M	1320*	500	1470	156
	95%CI	1304-1336	473-528	1448-1493	153-159
	S	1.09	1.63	1.14	1.17
	N	202	306	279	275
	Nu	202	306	279	275
	R	1100-1850	126-851	271-2020	92-211
Total Coliforms, MPN/100 ml	M	0.05	0.01		
	95%CI	0.001-2	0.001-0.07		
	S	4.5	40		
	N	101	137		
	Nu	3	17		
	R	<1-2	<1-260		
Fecal Coliforms, MPN/100 ml	M	<1	<1		
	95%CI	-	-		
	S	-	-		
	N	102	130		
	Nu	0	0		
	R	<1	<1		
B, mg/l	M	0.53	0.38		
	95%CI	0.47-0.6	0.35-0.42		
	S	1.37	1.34		
	N	27	39		
	Nu	27	39		
	R	0.2-0.9	0.2-0.6		

*Distribution falls outside 10% K-S limits.

(TABLE F-2B CONT.)

TABLE F-2B CONT.

Constituent	Parameter	Final Effluent Q9 3/1/78-12/31/78	Injection Water Q10 3/1/78-12/31/78	R.O. Influent Q22A 3/1/78-12/31/78	R.O. Effluent Q22B 3/1/78-12/31/78
Ca, mg/l	M				
	95%CI				
	S				
	N				
	Nu				
	R				
F, mg/l	M	0.81	0.57		
	95%CI	0.75-0.88	0.51-0.64		
	S	1.22	1.44		
	N	27	40		
	Nu	27	40		
	R	0.5-1.1	0.3-1.2		
Mg, mg/l	M				
	95%CI				
	S				
	N				
	Nu				
	R				
Org-N, mg/l	M	1.09	0.43		
	95%CI	0.99-1.2	0.38-0.48		
	S	1.51	2.24		
	N	76	183		
	Nu	76	183		
	R	0.4-2.5	0.1-2.7		
NH_3-N, mg/l	M	0.80	0.30		
	95%CI	0.56-1.1	0.23-0.4		
	S	6.10	5.74		
	N	117	183		
	Nu	97	144		
	R	<0.01-8.5	<0.01-3.9		
Turbidity, TU	M		0.28		
	95%CI		0.27-0.29		
	S		1.53		
	N		306		
	Nu		306		
	R		0.1-0.95		

(TABLE F-2B CONT.)

TABLE F-2B. CONT.

Constituent	Parameter	Final Effluent Q9	Injection Water Q10	R.O. Influent Q22A	R.O. Effluent Q22B
		3/1/78-12/31/78	3/1/78-12/31/78	3/1/78-12/31/78	3/1/78-12/31/78
NO_3^- -N, mg/l	M	7.7	2.5	6.3	3.3
	95%CI	5.8-10.2	1.8-3.4	4.6-8.9	2.5-4.4
	S	2.01	2.71	2.31	2.02
	N	27	37	27	26
	Nu	27	37	27	26
	R	0.4-15	0.2-11.3	0.3-18.7	0.2-6.7
Na, mg/l	M		70		
	95%CI		57-86		
	S		1.77		
	N		31		
	Nu		31		
	R		21-130		
Cl, mg/l	M		69		
	95%CI		54-88		
	S		1.94		
	N		31		
	Nu		31		
	R		16-195		
SO_4, mg/l	M		43		
	95%CI		25-75		
	S		4.30		
	N		29		
	Nu		29		
	R		3-223		
Total Hardness, mg/l as $CaCO_3$	M		64		
	95%CI		44-92		
	S		2.72		
	N		31		
	Nu		31		
	R		8-328		
TDS, mg/l	M	849	280		77
	95%CI	806-894	215-365		71-83
	S	1.11	2.04		1.21
	N	18	30		27
	Nu	18	30		27
	R	770-1060	68-520		53-114

(TABLE F-2B CONT.)

TABLE F-2B. CONT.

Constituent	Parameter	Final Effluent Q9	Injection Water Q10	R.O. Influent Q22A	R.O. Effluent Q22B
		3/1/78-12/31/78	3/1/78-12/31/78	3/1/78-12/31/78	3/1/78-12/31/78
MBAS, mg/l	M	0.08	0.036		
	95%CI	0.05-0.12	0.027-0.048		
	S	1.75	1.85		
	N	14	28		
	Nu	11	20		
	R	<0.03-0.2	<0.03-0.12		
Phenol, µg/l	M		0.60		
	95%CI		0.29-1.24		
	S		2.95		
	N		30		
	Nu		11		
	R		<1.0-8		
Cyanide, µg/l	M	6.9	1.9		
	95%CI	4.4-10.9	1.3-2.8		
	S	2.65	2.71		
	N	20	32		
	Nu	20	30		
	R	0.3-26	<0.1-7.9		
Color, units	M	0.8	7		
	95%CI	0-10[6]	5-10		
	S	4.19	2.14		
	N	17	29		
	Nu	2	23		
	R	<5-10	<5-25		

APPENDIX G

COMPARISON BETWEEN NORMAL AND LOGNORMAL DISTRIBUTIONS OF DATA AT VARIOUS SAMPLING POINTS DURING PERIODS TWO AND THREE*

Meaning of Symbols Used:

0 - both distributions fit within K-S boundaries equally well

L - lognormal distribution fits best, both within K-S boundaries

L - lognormal distribution fits within K-S boundaries, normal does not

N - normal distribution fits best, both within K-S boundaries

N - normal distribution fits within K-S boundaries, lognormal does not

X - neither distribution fits within K-S boundaries

Period Designations:

Under each sample location, two distributions may be indicated, that on the left is for period two, that on the right is for period three.

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*Only distributions with at least 8 data points above detection limits used.

TABLE G-1. DISTRIBUTION COMPARISON FOR ORGANIC CONTAMINANTS

Contaminants	Nature of Distribution											
	Q1	Q2	Q4	Q6	Q8	Q9	Q7-5	Q7-12	Q21A	Q21B	Q22A	Q22B
Chloroform	L	O	O L	N L	L	L	L	L	L	L L	L	L
Bromodichloromethane	L	O		N L	L	L	L	L	O	L O	N	O
Dibromochloromethane	L	O		O L	L	L	L		O	O	O	O
Tribromomethane	L	O		L N		O			O	O	O	
Carbon tetrachloride				O		O						O
1,1,1-Trichloroethane	L	N	O L	L	O	L	L		O	N	L	L
Trichloroethylene	L	O				O			O	O	N	N
Tetrachloroethylene	L	O				O			O	O	N	N
Chlorobenzene	O L	L L	O	O	L	L	O	L	O	O	O	L
1,2-Dichlorobenzene	O L	L N	O	O	L				N	O		
1,3-Dichlorobenzene	L L	L O				O			O	O		
1,4-Dichlorobenzene	L L	O O	O	O	N				O	O		
1,2,4-Trichloro-benzene	O L				L					O		
Ethylbenzene	L L	L		L	L	O			L	L		
Styrene	O											
m-Xylene	L	L	O	L		O	O	L	O	L	O	L
p-Xylene	O	L										
Naphthalene	L L			O	L					O		
1-Methylnaphthalene	O O				O							
2-Methylnaphthalene	O L								O			
Heptaldehyde	O			O		O						
Dimethylphthalate	O	O	O	L		L	O	O	L	L		L
Diethylphthalate	L			O						O		
Di-n-butylphthalate	O					O			O	L		L
Diisobutylphthalate	L	O	O	O		L			O	O		
Bis-[2-ethylhexyl]-phthalate	L											
PCB as Aroclor 1242	O	O							O			
Lindane	N			L								

TABLE G-2. DISTRIBUTION COMPARISON FOR GENERAL PARAMETERS AND INORGANIC CONTAMINANTS

Contaminant	Nature of Distribution								
	Q1	Q2	Q4	Q6	Q8	Q9	Q10	Q22A	Q22B
COD	O	O		O	N		L	L	O
TOC	O N	O O		O O	L L			O	O
Turbidity	L X	L L	L	L L		O	L L		
Organic-N	L L	L L	L L			X O	L L		
Ammonia-N	X L	X L	L L		N	X N	X N		
Electroconductivity	X X	L X	L			O X	X X	L X	X N
B	L L	L				O O	N O		
Ca	X	L	O		O	O	L		
F	O O					O O	O		
Mg	O	L				L	O		
Ag	N O	L L		L	L		N L		
Ba	L O	L O		L	L		L N		
Cd	L N	L O		O	L		O N		
Cr	L O	L O		L	L		L L		
Cu	O O	O N		O	O		L L		
Fe	L O	L O		L L	L		L L		
Hg	L	L		X	L		X		
Pb	L O	O		L	L		L L		
Zn	L	N		L	N		X		